Composition and application prospect of several novel quantum dot-polymer composites

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Abstract. In this paper, we will extensively discuss the research and future prospects of quantum dot-polymer composites, while also highlighting notable examples from existing studies. By examining the unique synergies between quantum dots and polymers, we aim to shed light on the advantages and significance of this composite approach in various domains. Our study will carefully analyze previous research endeavors, aiming to explore the diverse range of quantum dot-polymer composite materials. Through this exploration, we will elucidate the emergence of novel properties and functionalities resulting from this innovative combination. By showcasing successful instances of quantum dots integrated into polymer matrices, we endeavor to establish a comprehensive understanding of the immense potential held by these composites. By uncovering the synergistic effects between these two materials, we hope to inspire further advancements and collaborations in this exciting field. By delving into the successful integration of quantum dots within polymer matrices, we aim to emphasize the transformative potential of these composites. Their ability to combine the exceptional characteristics of both quantum dots and polymers open new avenues for advanced technologies and applications.

Keywords: Quantum Dots, Semiconductor Nanocrystals, Composite Materials, Polymer Matrices, Application Prospects.

1. Introduction

Quantum dots (QDs) have emerged as a remarkable class of semiconductor nanocrystals, exhibiting exceptional optical properties that hold immense promise in the realm of optoelectronic advanced materials [1]. These highly efficient photosensitizers have paved the way for a plethora of potential applications ranging from photovoltaic devices to molecular electronics and photocatalysts [2].

Quantum dots are nanoscale semiconductor materials that manifest themselves in spherical forms, typically ranging between 2 and 20 nanometers in diameter. When energized by light or electricity, quantum dots undergo the photoelectric effect, allowing them to emit light of a specific frequency. It is crucial to note that the wavelength of this emitted light directly correlates with the radius of the quantum dot, offering a means to precisely control the wavelength by manipulating the size of these minuscule structures [1, 3, 4].

However, as micro-particle materials, quantum dots often necessitate their integration with other substances to form composite materials that can be employed in practical applications. Unfortunately, the matrix materials conventionally combined with quantum dots primarily entail microscopic metal

frameworks or metal nanorods, which have several drawbacks, including exorbitant costs and complex processing methods [5, 6].

In contrast, polymers, renowned for their versatility and vast array of properties, proffer a compelling alternative as composite matrices for quantum dots. These polymeric materials boast remarkable attributes such as excellent mechanical properties, chemical stability, and cost-effectiveness. Consequently, leveraging polymers as a matrix for quantum dot composites presents an outstanding avenue to expand the horizons of research and applications [7].

In this paper, we aim to shed light on the research and application prospects of quantum dot-polymer composites by presenting noteworthy examples from existing studies. By exploring the unique synergies between quantum dots and polymers, we can discern the advantages of this composite approach and elucidate its significance in various domains [8].

Through a meticulous examination of previous research endeavors, we will delve into the diversification of quantum dot-polymer composite materials, elucidating the novel properties and functionalities that arise from this innovative combination. By showcasing the successful integration of quantum dots within polymer matrices, we intend to forge a comprehensive understanding of the vast potential harbored by these composites.

2. Literature Review

For a long time, composite material construction has been increasingly adopted due to the limitations of a single material in performance, as it allows for the integration of multiple material characteristics [9]. Polymer, as a matrix material, has gained widespread usage in various engineering fields owing to its favorable mechanical properties, lower density compared to metals, and ease of processing [8]. Polymer matrix composites can be enhanced with nanoparticles, including quantum dots, which offer exciting possibilities for polymer-quantum dot composites.

This review paper focuses on three specific applications of polymer-quantum dot composites: composite coatings, composite films, and polymer sensors. The remarkable properties of both polymers and quantum dots make them well-suited for these applications, where their synergistic effects can be harnessed [10].

In the realm of lubricants, carbon quantum dots have emerged as significant materials that have captured substantial attention. These cost-effective nanoparticles exhibit exceptional physical properties and chemical stability, enabling them to effectively reduce surface friction and prevent damage to metal components [11]. Simultaneously, polyimide, a commonly utilized polymer coating material, has encountered challenges related to dispersion. Incorporating carbon quantum dots not only addresses this problem but also introduces a novel functional material into the field of functional coatings [12].

Moreover, quantum dots have found wide application in the domain of flexible electronics due to their excellent photoelectric properties. Researchers have successfully utilized quantum dots and polymer films to create flexible thin film structures with carefully designed spatial arrangements, thereby enabling their use as photodetectors [13]. This innovative film material holds great promise for applications in wearable devices, where flexibility and light weight are essential.

The third application discussed in this review paper combines the chemical properties of polymers with the photoelectric properties of quantum dots. Molecular imprinting technology utilizes polymers as core functional materials, enabling specific identification of target molecules. This technology, widely employed in biochemistry and medicine, offers easy synthesis, good chemical stability, and widespread applications. By embedding quantum dots as luminescent markers in molecularly imprinted polymers, improved performance can be achieved compared to traditional luminescent embedding materials [14, 15].

In summary, the use of polymer-quantum dot composites opens up exciting opportunities across various fields. Composite coatings, composite films, and polymer sensors leverage the complementary properties of these two materials, leading to enhanced functionalities. The incorporation of carbon quantum dots in lubricants addresses friction-related challenges, while the integration of quantum dots into flexible thin films creates advanced photodetection capabilities for wearable devices. Additionally,

combining quantum dots and polymers in molecularly imprinted polymers enhances their performance in bioscience and medical applications, facilitating improved diagnostics and sensing capabilities. The continuous exploration and advancement of polymer-quantum dot composites hold immense potential in diverse fields, propelling progress and innovation.

3. Methodology

In this review paper, ScienceDirect and Google Scholar were used as data collection platforms to collect secondary data and analyze the research conducted in the field of polymer-quantum dot composites while searching for application information on polymer-quantum dot composites.

The first step in this approach is to identify the data collection platforms - ScienceDirect and Google Scholar. These platforms were chosen because of the wide range of scholarly articles and publications in various subject areas, resulting in a comprehensive review of relevant literature in the field.

The next step is to determine the criteria for selecting research articles from the large amount of available literature. In this study, the selection criteria are based on three main areas: composite film, composite coating and polymer sensor [3, 4, 8]. These areas cover the different construction forms and application areas of polymer quantum dot composites. Description of these areas allows for a systematic review of the literature and a comprehensive analysis of various applications.

During the search process, specific inclusion and exclusion criteria should be used to filter the initial search results. The screening process removes articles not considered or related to the research direction, ensuring that only the most relevant and reliable articles are included in the review.

After a screening process, the selected articles are read in detail, and a series of key information, including research objectives, methods, results and conclusions, are extracted. This information is organized in a systematic way for further analysis and discussion.

Then the topic method is used to analyze the reviewed articles. These topics are derived from the areas identified earlier in the methodology. The analysis includes examining similarities, differences, and emerging patterns in the findings of the selected articles. This method can identify the status quo, trends and gaps in the different fields of application of polymer quantum dot composites.

Finally, this paper gives a comprehensive and comprehensive introduction to the results of the literature review. The Research Methods section explains in detail the steps taken to collect and analyze the data to ensure transparency and reproducibility of the research.

4. Result

For the ZnO nanorods-ZnO quantum dots-polymer composite film, the surface arrangement of this material made by the spinning coating process is dense and smooth. This material has good optical properties and meets the performance requirements of its intended planning [4].
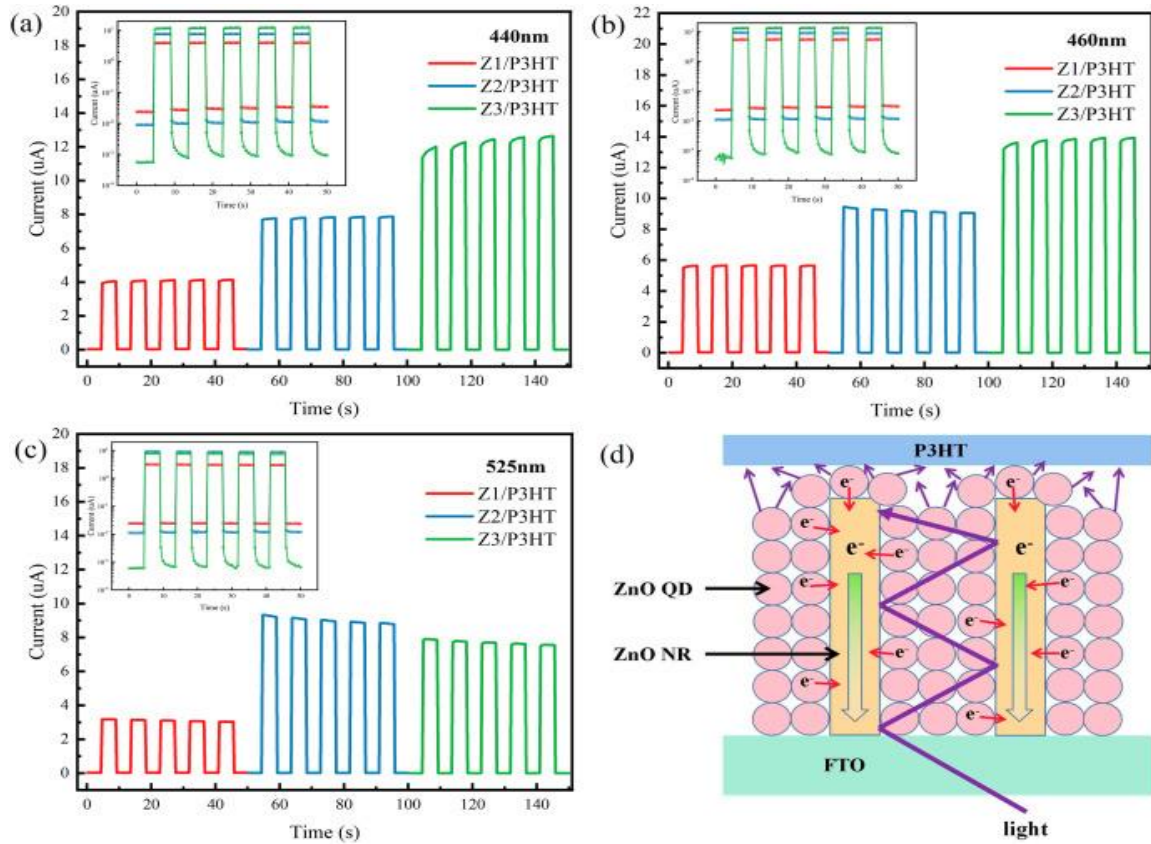
Figure 1. The logarithmic time curve of a, b and c films of three different specifications under alternating illumination at 440nm, 460nm and 525nm wavelengths, respectively. d Film device working principle diagram under light [4].

For carbon quantum dot-polyimide composites, this material has excellent thermal stability and mechanical properties. It has good hardness and anti-friction properties. The average friction coefficient of pure polyimide is about 0.37, while the lowest average friction coefficient of 1 wt% CQD/PI is about 0.24, which is about 33.3% lower than that of pure polyimide. Under the same test conditions, the wear rate of pure PI is $4.75\times10{-}5$ mm 3/ (Nm), as shown in Figure 2 (b). The PI wear rate, including 1wt%CQD was reduced by 63%. The results show that CQDs play an important role in enhancing the antifriction and wear resistance of PI, including CQDs particles [3].
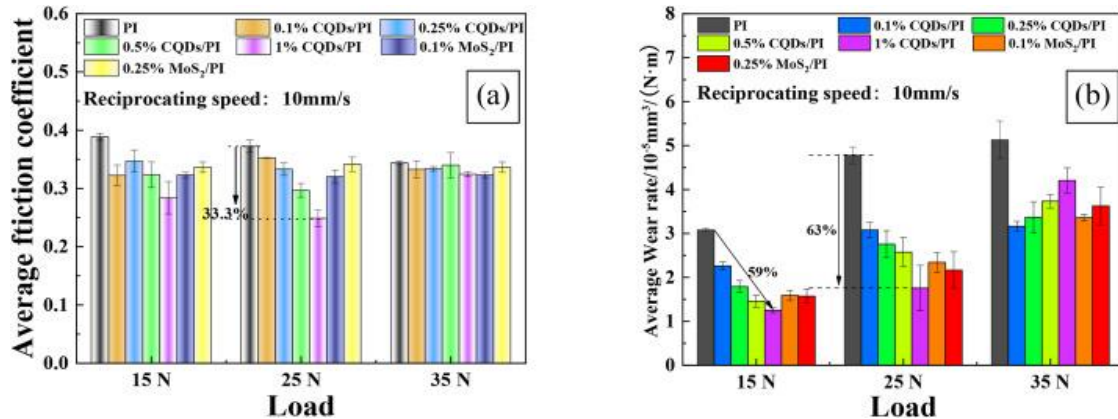

Figure 2. Performance data under different load conditions. (a) Average friction coefficients; (b) average wear rates [3].

For imprinted polymer sensors, MIPs@RPQDs/GPQDs@SiO2 and NIPs@RPQDs/GPQDs@SiO2 show two fluorescence peaks at 520 nm and 695 nm. When Rhein is added to the MIPs@RPQDs/GPQDs@SiO2 solution, the fluorescence intensity of GPQDs at 520 nm remains unchanged and RPQDs at 695 nm gradually decay. This is because the GPQDs were well wrapped in SiO2 to avoid interaction with the drug, so the fluorescence intensity remains highly stable. However, the surface of MIPs@RPQDs/GPQDs@SiO2 has abundant imprinting cavities, and it can accurately identify Rhein and quench the fluorescence of RPQDs through the interaction of drugs and materials. During this process, the fluorescence color of MIPs@RPQDs/GPQDs@SiO2 changed from red to blue-green. This phenomenon indicates that MIPs@RPQDs/GPQDs@SiO2 plays a crucial role in identifying Rhein. Whether there is Rhein or not can also be judged by observing the change of fluorescence color directly under ultraviolet light. After the template is eluted, the fluorescence intensity of MIPs@RPQDs/GPQDs@SiO2 is restored to the same level as that of NIPs@RPQDs/GPQDs@SiO2. It shows that the eluent selection is effective [14].
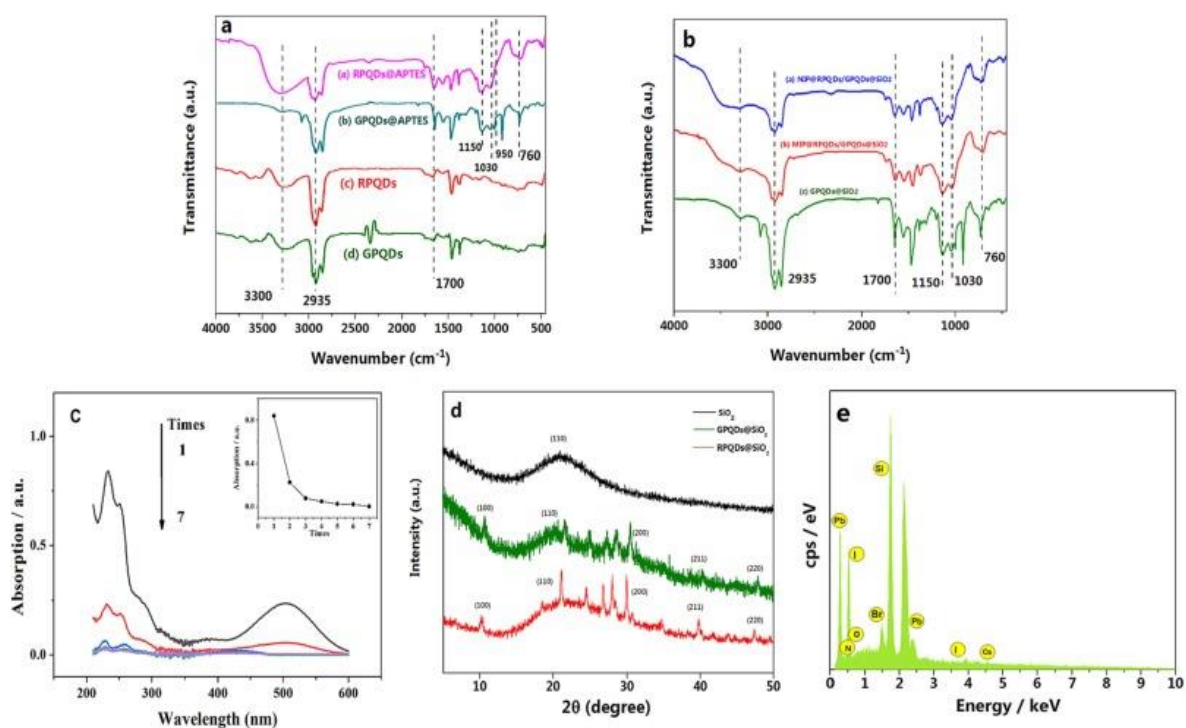

Figure 3. The FT-IR spectra of (a) RPQDs, GPQDs, APTES-capped RPQDs, APTES-capped GPQDs and (b) GPQDs@ SiO2, MIPs@RPQDs/GPQDs@SiO2 and NIPs@RPQDs/GPQDs@SiO2. (c) UV absorption spectra of Rhein with different elution times (Insert: absorption of Rhein as a function of elution times). (d) XRD patterns of SiO2, RPQDs@SiO2, and GPQDs@SiO2. (e) EDS spectrum of MIPs@RPQDs/GPQDs@SiO2 [14].

5. Discussion

This paper investigates the potential applications of three quantum dot-polymer composites: carbon quantum dot-polymer lubrication coatings, Zno-polymer composite films, and molecularly imprinted polymers embedded with quantum dots. The results show that these composites have great prospects in mechanical lubrication, flexible optoelectronic devices and molecular imprinting recognition. These materials may attract the attention of chemical and optoelectronics engineers interested in applying quantum dot composites. If they don't read this article, they may miss the latest cutting-edge advances in quantum dot composites.

Firstly, carbon quantum dot-polymer lubrication coating is an advanced lubrication material with great potential. When carbon quantum dots are added to the polymer matrix, the lubrication performance

and wear resistance of the coating are significantly improved, and the friction coefficient and wear rate are reduced. Carbon quantum dots have unique properties such as high surface area, good dispersion and surface chemistry for improved lubrication, helping to reduce friction and wear. These findings make carbon quantum dot-polymer lubrication coatings a promising candidate for a variety of mechanical lubrication applications, including automotive engines, industrial machinery, and micro/nano-electromechanical systems (MEMS/NEMS).

Secondly, Zno-polymer composite films show excellent performance in the development of flexible optoelectronic devices. By combining ZnO nanoparticles with polymers, a composite material with light collection, charge transport and mechanical flexibility was formed. These composite films demonstrate impressive optical and electrical properties, including high optical response, excellent carrier mobility and bendability. Therefore, Zno-polymer composite films can play a role in applications such as flexible solar cells, wearable electronics and displays. In addition, this composite material is compatible with low-cost manufacturing techniques, further increasing the attractiveness of manufacturing large-scale and low-cost optoelectronic devices.

Thirdly, molecularly imprinted polymers embedded with quantum dots are a major breakthrough in the field of molecular imprinting recognition. By embedding quantum dots into molecularly imprinted polymers, the composites have high selectivity and sensitivity to the target molecules. The interaction between the target molecule and the recognition site within the imprinted polymer results in fluorescence quenching or color change, enabling rapid and visual detection. This innovative approach opens up new avenues for molecular imprinting techniques, providing enhanced detection capabilities and reliability. Molecularly imprinted polymers embedded with quantum dots have great potential applications in molecular sensing, environmental monitoring and biomedical diagnostics [15].

In summary, carbon quantum dot-polymer lubrication coatings, Zno-polymer composite films and molecularly imprinted polymers embedded with quantum dots show broad application prospects in mechanical lubrication, flexible optoelectronic devices and molecularly imprinted recognition. These new composites offer improved functionality and performance over single materials, driving progress across multiple industries.

6. Conclusion

In the field of mechanical lubrication, carbon quantum dot-polymer lubrication coatings show extraordinary potential. With its unique composition and properties, this composite material has enhanced lubrication properties, reducing friction and wear in mechanical systems. The integration of carbon quantum dots into the polymer matrix can improve the carrying capacity and reduce energy loss. These advantages have the potential to revolutionize mechanical systems, extending their service life and improving overall efficiency and performance.

In the field of flexible optoelectronic devices, ZnO-polymer composite films show an exciting combination of properties. These films are inherently flexible and transparent due to the incorporation of zinc oxide nanoparticles into the polymer matrix. This remarkable convergence has made possible the development of flexible, lightweight and efficient electronic devices, including wearable technology, flexible displays and solar cells. Harnessing the potential of these composite films opens up huge possibilities for realizing future electronic applications.

In the field of molecular imprinting recognition, quantum dots embedded in molecularly imprinted polymers show extraordinary ability. By embedding quantum dots in polymer structures, these materials provide selective recognition and binding sites for specific target molecules. This molecular imprinting method provides an innovative solution for highly sensitive and specific detection in areas such as biosensing, environmental monitoring and pharmaceutical applications. The integration of quantum dots provides a refined platform for signal amplification and high-affinity binding, which improves the efficiency of molecular recognition.

While these quantum dot polymer composites show great potential, it is critical to understand and address their limitations. One obvious obstacle is the scalability of the manufacturing method. Current technology has effectively reduced production costs, but achieving mass production remains to be tested.

To overcome this challenge, future research efforts should focus on improving and optimizing manufacturing processes, and exploring alternative approaches to ensure cost-effectiveness, repeatability, and applicability outside of controlled laboratory environments. By overcoming scalability barriers, these materials can evolve from promising concepts to practical solutions for industrial applications. In addition, the limitations of this study include the dependence of ZnO-polymer films on ZnO nanorods. This material increases the cost and increases the difficulty of large-scale applications [3].

Another notable aspect of this study is its reliance on secondary sources. While a comprehensive analysis of the existing literature provides valuable insights, direct experimental knowledge is essential to a thorough understanding of these composites. The researchers must conduct extensive experimental investigations to validate and reinforce the findings, leading to a more comprehensive assessment of the material's properties, properties, and potential optimizations.

Carbon quantum dot-polymer lubrication coating, Zno-polymer composite film and quantum dot-embedded molecular imprinting polymer have great application prospects in mechanical lubrication, flexible optoelectronic devices and molecular imprinting recognition, respectively. However, addressing the challenges associated with scalability and the need for direct experimental knowledge is a critical step.

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