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Advancement in Quantum Dots Research: Expending Applications and progress in Synthesis, Characterisation and coordination with benzimidazole for its medicinal property

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Abstract

Quantum dots (QDs) have emerged as promising nanomaterials with unique optical and electronic properties, making them highly attractive for a wide range of applications. This abstract presents recent advancements in QDs research, focusing on the expansion of their applications, progress in synthesis and characterization techniques, and their coordination with benzimidazole for potential anticancer and other medicinal properties. QDs have shown remarkable potential in various fields, including optoelectronics, biological imaging, solar cells, and drug delivery. Their tunable emission wavelengths and high photostability have facilitated their integration into diverse applications, leading to improved device performance and diagnostic capabilities. Furthermore, significant progress has been made in the synthesis and characterization of QDs, enabling precise control over their size, shape, composition, and surface properties. These advancements have enhanced their stability, biocompatibility, and bioconjugation efficiency, enabling their utilisation in biomedical applications. In recent studies, Benzimidazole-based compounds have demonstrated remarkable antitumor activity due to their ability to inhibit crucial cellular pathways involved in cancer progression. By combining the unique optical properties of QDs with the therapeutic potential of benzimidazole derivatives, novel multifunctional systems have been developed for targeted cancer imaging, therapy, and theranostics. Overall, this abstract highlights the expanding applications of QDs, the progress in synthesis and characterization techniques, and the synergistic potential of coordinating QDs with benzimidazole derivatives for medicinal properties. These advancements hold great promise for the development of next-generation nanomedicine platforms for improved cancer diagnosis and therapy.

Keywords: **Benzimidazole, Quantum Dots, Medicinal Property**

Introduction

Since many years reduced dimensionality of semiconductors, which led it upto the concept of QDs (Quantum Dots)[1,2] The coordination of quantum dots (QDs) with imidazole ligands for anticancer medicinal purposes is an area of research that combines the unique properties of QDs[3] with the potential therapeutic applications of benzimidazole-based compounds. Benzimidazole ligands are organic molecules that can coordinate with metal ions, forming coordination complexes. These complexes have been studied for their potential in various medicinal applications, including cancer treatment. The ability to coordinate benzimidazole[4] ligands with QDs opens up new possibilities for targeted drug delivery and imaging in cancer therapy. By functionalizing QDs with benzimidazole ligands, researchers aim to achieve several goals. First, the QDs can act as carriers for delivering anticancer drugs or therapeutic agents to specific tumour sites. The coordination between the QDs and benzimidazole ligands can enhance the stability and biocompatibility of the drug-loaded QDs, improving their efficacy and reducing potential side effects. Additionally, the fluorescence properties of QDs can be utilized for imaging and diagnostics. QDs have unique optical properties, including tunable emission wavelengths and high photostability. By coordinating QDs with benzimidazole ligands, researchers can develop imaging probes that specifically target cancer cells[6] or tumor tissues[7], allowing for accurate visualization and detection of tumors. The coordination of QDs with benzimidazole ligands for anticancer medicinal purposes[8] requires careful design and characterization. The choice of QD material, size, and surface functionalization, as well as the selection of appropriate benzimidazole ligands[9], all play crucial roles in determining the properties and performance of the resulting complexes[5]. Overall, this interdisciplinary approach combining QDs and benzimidazole ligands holds great promise in advancing cancer therapeutics and diagnostics. By harnessing the unique properties of

both QDs and benzimidazole-based compounds, researchers aim to develop more targeted and effective treatments for cancer[10], while also providing valuable imaging tools for disease detection and monitoring.

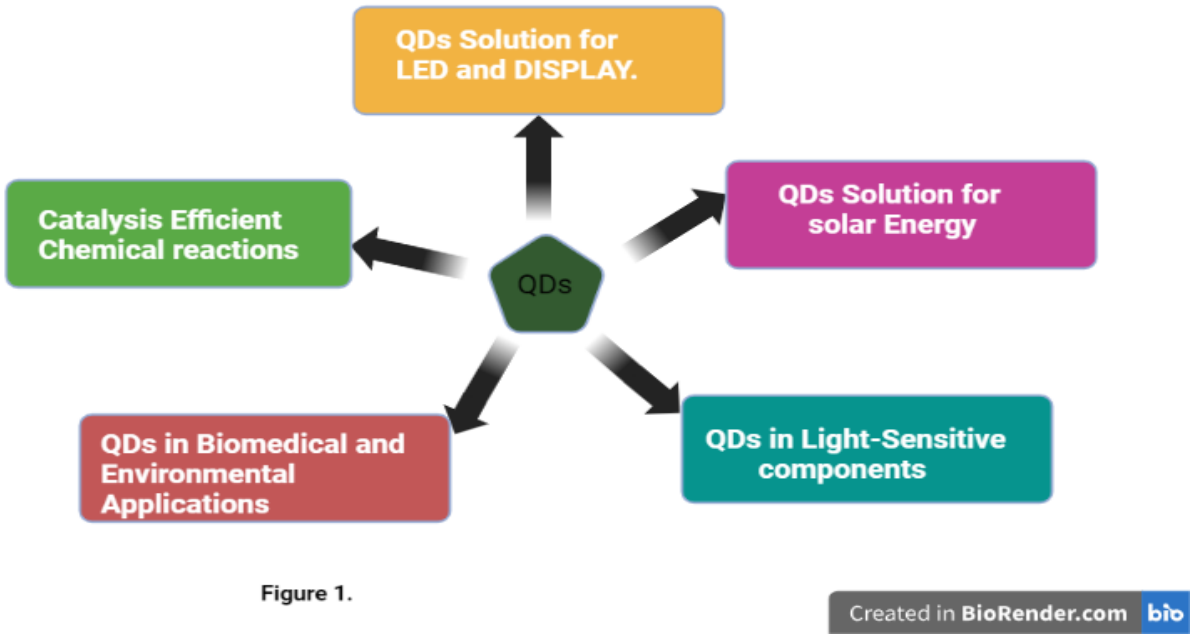

Fig.1. Advancement and uses of QDs

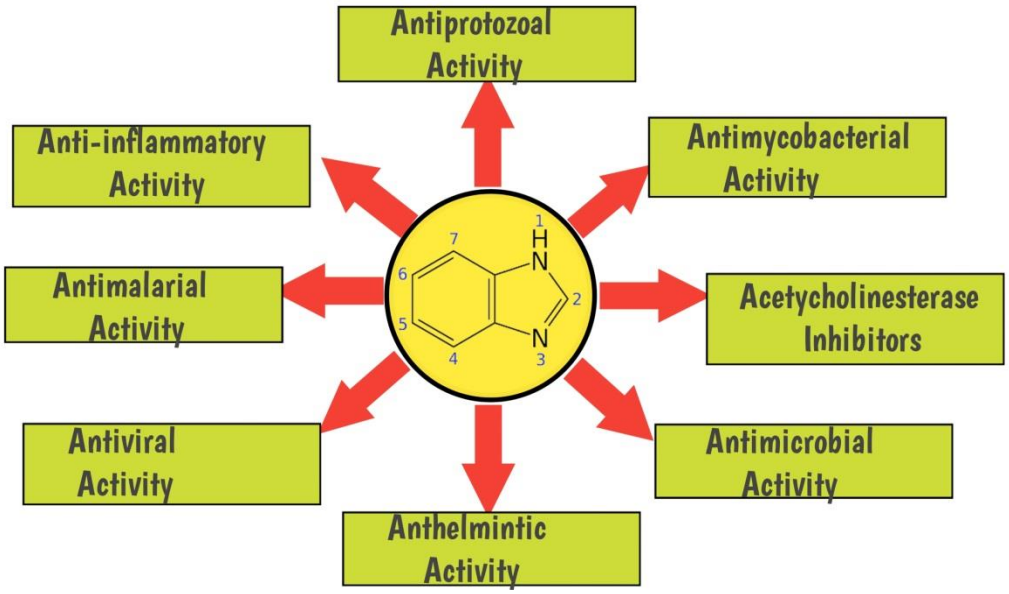

Fig. 2. Medicinal Properties of Benzimidazole

1. **QDs in Biomedical and Environmental Applications: Health and ecosystem advancements through Technology.**

Quantum dots (QDs) are semiconductor nanocrystals with unique optical and electronic properties, making them ideal for diverse applications in medicine. By functionalizing QDs with benzimidazole ligands, their stability, biocompatibility, and specificity can be enhanced, opening up new possibilities in bioimaging, targeted drug delivery[11], photodynamic therapy, and sensing/diagnostics. In bioimaging[41], QDs with benzimidazole ligands[12] act as fluorescent labels for precise imaging of cells[42], tissues, or biomolecules. In targeted drug delivery, these ligands enable selective binding to specific cells or tissues, allowing QDs to serve as carriers for

therapeutic agents. Moreover, benzimidazole ligands can be used to incorporate photosensitizing agents[13] into QDs for photodynamic therapy, which involves localized cell damage[14] upon exposure to specific wavelengths of light. Additionally, QDs functionalized with benzimidazole ligands can be utilized in sensing platforms to detect biomolecules or analytes, thanks to the ligands' selective binding affinity towards specific targets. While this field is still actively researched, advancements in the design and properties of ligand-QD complexes continue to expand their potential for medicinal applications[15,16]

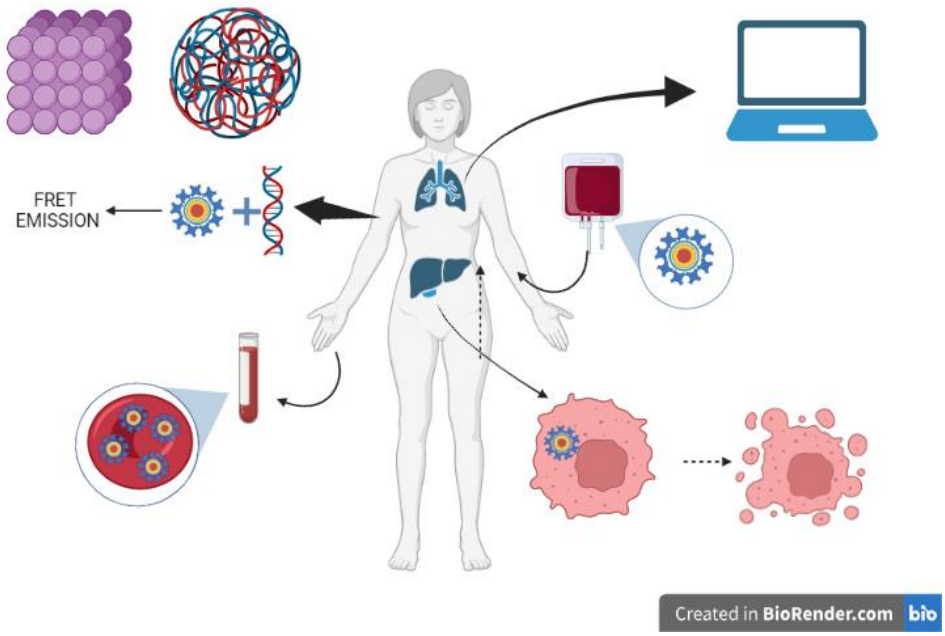

Fig. 3. Medicinal uses of QDs in Human Body (Created with Biorender.com)

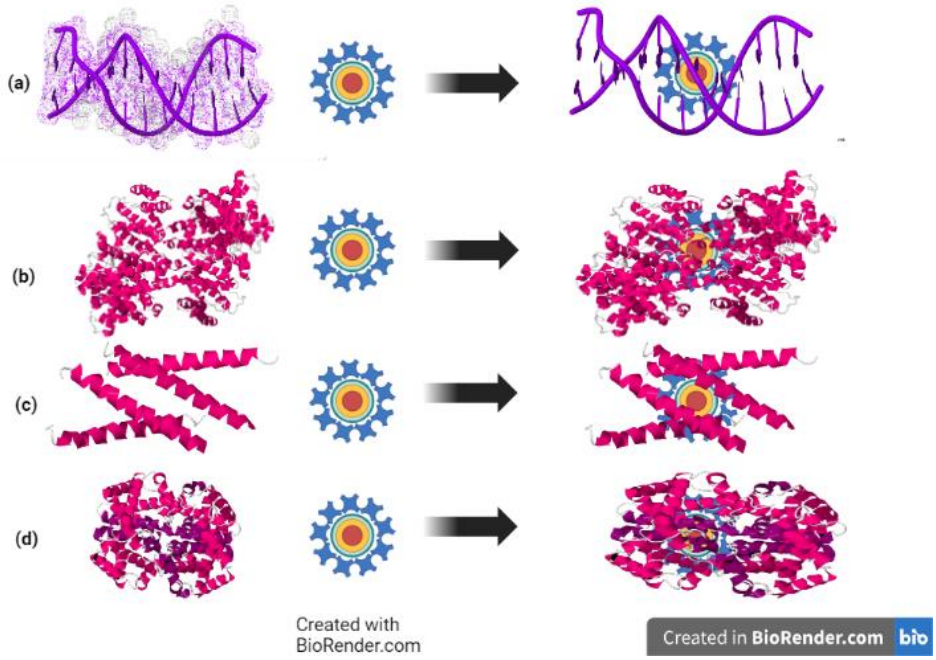

Fig. 4. (a). DNA with QDs . (b) Liver Protein Albumine with QDs. (c) Glycophorin Proteinwith QDs (d). Hb Protein with QDs

Benzimidazole ligands can indeed be used to functionalize quantum dots for various medicinal applications. Quantum dots are semiconductor nanocrystals with unique optical and electronic properties, and they have garnered significant interest in the field of medicine[13] due to their potential in imaging, drug delivery, and therapeutics. Benzimidazole ligands are organic molecules containing a benzene ring fused with an imidazole ring[6]. These ligands can be designed to possess specific functional groups that allow them to bind to the surface of quantum dots, forming a stable complex. The interaction between the ligand and the quantum dot surface can be facilitated through coordination bonds, van der Waals forces, or other interactions. By functionalizing quantum dots with benzimidazole ligands, several medicinal properties[15] can be achieved.

(a). Bioimaging: Quantum dots possess excellent fluorescence properties, and the addition of benzimidazole ligands can enhance their stability and biocompatibility. This makes them suitable for applications such as fluorescent labeling of cells, tissues, or biomolecules for imaging purposes.

(b). Targeted drug delivery: Benzimidazole ligands can be conjugated with specific targeting moieties, such as antibodies or peptides, to enable selective binding to particular cells or tissues. Quantum dots functionalized with these ligands can act as carriers for drugs or therapeutic agents, allowing precise delivery to the desired location.

(c). Photodynamic therapy (PDT): Benzimidazole ligands can be used to functionalize quantum dots with photosensitizing agents. In PDT, these complexes can generate reactive oxygen species when exposed to light of a specific wavelength, leading to localized cell damage and targeted therapy for diseases such as cancer.

(d). Sensing and diagnostics: Quantum dots functionalized with benzimidazole ligands can be used in sensing platforms to detect specific biomolecules or analytes. The ligands can be engineered to exhibit selective binding affinity towards certain targets, enabling the sensitive detection of diseases or environmental contaminants[17]. It's worth noting that the field of using quantum dots and benzimidazole ligands for medicinal applications is still an active area of research, and many advancements are being made. The specific design and properties of the ligand-quantum dot complex would depend on the desired application and the specific characteristics of the quantum dot being used

2. QDs Solution for LED and DISPLAY Application

Early LED technology was primarily based on III-V heterostructures, which later incorporated epitaxial quantum dots (QDs). These QDs are naturally integrated into a multilayer heterostructure grown on a semiconductor substrate, unlike the colloidal synthesis method. Among the various material systems, InAs/GaAs QDs have been extensively studied. However, the high temperature during the growth process can lead to issues with interface control, such as In desorption. To tackle this problem, vertically coupled QD bilayers with a significant enhancement in photoluminescence (PL) intensity have been achieved by capping the QDs with self-assembled $In_xGa_{1-x}As$ layers[18]. Another challenge commonly encountered in epitaxial QD systems is postprocessing analysis. A novel approach to address this issue involves using chemically etched semiconductor nanomembranes and scanning tunneling spectroscopy[19]. In the realm of III-V compounds, solution-processed colloidal InP QDs have been explored for LED and display applications due to their tunable, bright, and narrow PL. Remarkable improvements have been achieved by adding a ZnSe/ZnS multishell to InP cores, making them suitable for wide color gamut display applications[20]. To expand our understanding, the surface dangling bonds of InP QDs have been studied using density functional theory (DFT) calculations combined with experimental evidence[21]. Different materials are utilized to obtain QDs emitting in specific spectral ranges. Silicene QDs confined in few-layer siloxene nanosheets with $FeC_{l3}\cdot 6H_2O$ have shown potential as emitters in blue-light-emitting diodes. Halide-exchanged $CsPb(Br/I)_3$ and CsPbI3 QDs exhibit enhanced structural and optical properties, making them suitable for LEDs with 670 nm emission. $CsPbBr_3$ QDs can also be employed to decorate ZnO nanorods on GaN films, enabling dual-wavelength green-light-emitting diodes[22]. Graphene oxide QDs/GaN composites have been shown to enhance the photoluminescence of GaN PL.[23]

For phosphors and white-light-emitting diodes, blue-emitting $CsPbBr_3$ QDs can be utilized[24], while hexagonal boron nitride sheets improve the thermal stability of CdSe/CdS QDs-based devices[25]. Researchers are also investigating ultrastable QD-based phosphors, as demonstrated by a LED encapsulated with a CdSe/CdS/ZnS QD-SiO_2/Al_2O_3 monolith phosphor[26]. White light had also been achieved using a nanocomposite complex of BSA (bovine serum albumin) and QDs, with zinc quinolate and zinc sulfide complexes as the QDs[27]. Additionally, ultrabright fluorescence and stable graphene QDs synthesized via microwave irradiation have been proposed as efficient alternatives for white-light-emitting diodes[28]. On the other hand, nontoxic zinc nitride (Zn_3N_2) colloidal QDs present a viable alternative for QD LED displays. The optical band gap of these QDs increases from 1.5 to 3.2 eV with decreasing size[29]. Thin-film-type LEDs can be based on $CsPbX_3$ QDs fabricated using a new solid-state ligand-exchange method[30]. CuInS2/ZnS QDs with stable thiol- and amine-based ligands are also suggested for efficient film-type display devices[31]. Polymer encapsulation of CdSe nanoplatelets and PbS QDs[32] shows potential for application as a composite material in LEDs. Furthermore, CdSe/CdS and CdSe/ZnS QD films coupled with Au nanorod dimer arrays can manipulate the polarization of the photoluminescence in luminescent films[33]

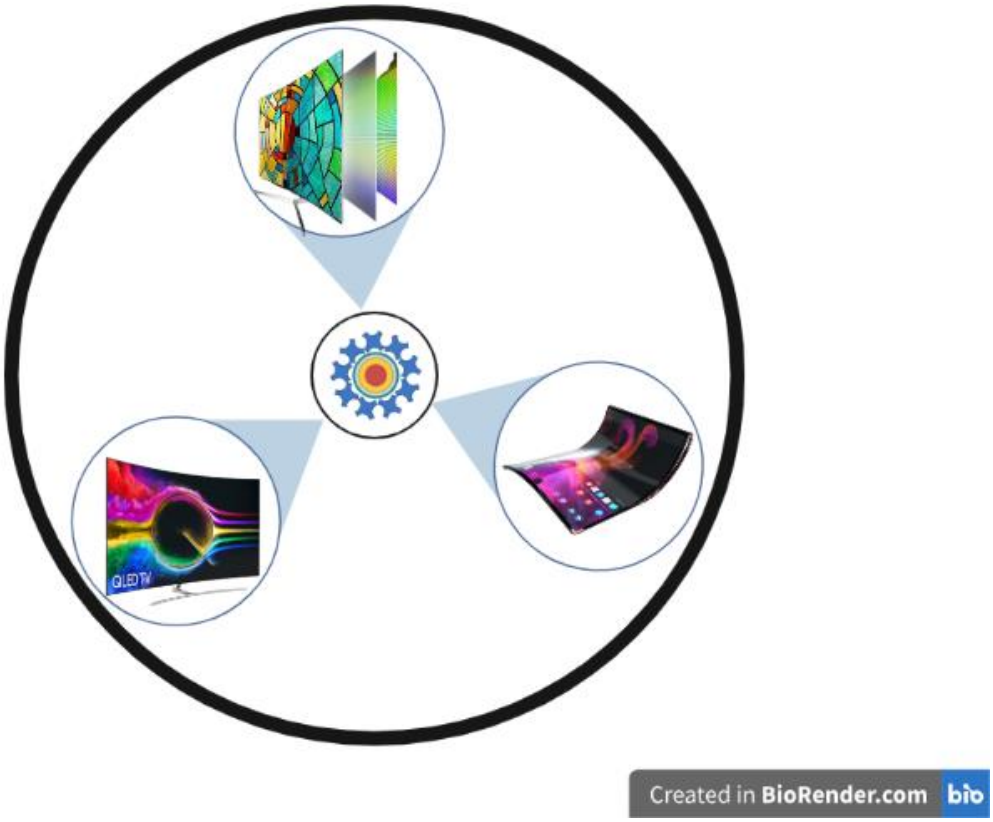

Fig. 5. Uses of QDs

3. **QDs Solution for solar Energy Conversion through Semiconductor.**

New techniques have been reported to enhance the energy conversion efficiency[34] in photovoltaic devices by incorporating nanomaterials. These include the use of CdS Quantum dots (QDs)[35], as well as CdSe and CdSe/CdS core-shell QDs[36]. Researchers have also developed novel method for capping PbS QDs with atomic ligands[37] and improving the passivation of CdSe/CdS/ZnS core-shell-shell QD thin films. Additionally ligand and solvent engineering have been employed to enhance the performance of PbS QDs films, which have also been studied in combination with ZnO films the homogeneous dispersion of core-shell CdS/ZnS QDs in copolymers has been achieved using supercritical carbon dioxide synthesis[38]. Theoretical studies using density functional theory (DFT) calculation have aided in the design of energy conversion materials based on CdSe QDs.

4. **QDs in Light-Sensitive Electronic components**

Various devices, including light-dependent resistors (photoconductors) and photodiodes, can be utilized for photon detection across different spectral ranges. To enhance the performance of these existing technologies, the integration of Quantum Dots (QDs) has proven successful. This integration has been particularly beneficial in the infrared (IR) region, where PbS QD photodetectors have demonstrated improved responsivity through a two-step ligand-exchange technique[39]. Additionally, photoconductors have been created using densely packed PbS QD films synthesized via a rapid microwave-polyol method, resulting in high responsivity midwavelength IR photodetectors. Ag_2Se QDs have also been employed to fabricate IR photoconductive photodetectors with notable responsivity. Printing techniques have further been applied to develop PbS QD-based devices, including broadband photoconductors and photodetector arrays[40]. In the ultraviolet (UV) spectral range, photodetectors have been successfully manufactured using a nanocomposite of WS_2 QDs and graphene. Furthermore, phototransistors featuring balanced photodetection have been achieved by utilizing $CsPbBr_3$ colloidal QDs and few-layer MoS_2. These advancements in QD integration have contributed to the development of efficient photodetection technologies across various spectral ranges.

5. **Catalysis: Efficient Chemical reactions using QDs**

Semiconductor photocatalysis technology harnesses the power of light to convert it into chemical energy. In this regard, researchers have been exploring the use of quantum dots (QDs) to enhance existing catalytic processes or create new ones. For instance, by incorporating carbon QDs into graphitic carbon nitride, scientists achieved photocatalytic hydrogen (H_2) evolution that maintained its activity for an extended period of six months without significant decay[43]. Another approach involved utilizing carbon QDs to sensitize TiO_2/Pt nanocomposites[44], resulting in light-driven H_2 generation. Moreover, N-doped graphene QDs produced through liquid-laser ablation in various aqueous solutions exhibited high catalytic selectivity for the oxygen (O_2) reduction reaction and the conversion of 4-nitrophenol to 4-aminophenol under near-infrared (IR) light[45]. Additionally, CdS QDs were utilised as catalysts for the photocatalytic synthesis of imines. Furthermore, quantum dots have found diverse applications beyond catalysis. For instance,

fluorescent CdTe QDs were combined with maghemite nanoparticles for magnetic particle inspection in ferromagnetic materials. QDs have also been used for encapsulation and nanotags, enabling the authentication of goods. By dispersing CdSe/ZnS QDs in liquid crystals, micrometer-sized capsules were obtained, which exhibited remarkable thermal stability up to 350 °C. Additionally, highly stable PbS and PbS/CdS QDs[46] with hybrid coatings were proposed as luminescent nanotags for liquid petroleum products. In conclusion, the field of quantum dots remains an active and vibrant area of research in applied nanomaterials. This represent a comprehensive selection of recent advancements in the field and provide a glimpse into the potential technological breakthroughs that can arise from these investigations.

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