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APPLICATIONS OF PLATINUM NANOPARTICLES AS CHEMICAL SENSOR FOR DETECTION OF METAL IONS AND PESTICIDES IN ENVIRONMENTAL SAMPLES

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ABSTRACT

This chapter explores the distinctive electronic and optical properties of platinum nanoparticles (PtNPs), which serve as effective chemical sensors for the selective and sensitive detection of harmful chemicals in environmental samples. Various toxic metal ions, including mercury, arsenic, lead, cadmium, and chromium, as well as several pesticides (such as chlorinated compounds and those containing phosphorus and nitrogen), pose significant risks to public health. To address this, different synthesis methods for PtNPs are employed, and these nanoparticles are functionalized to enhance their ability to detect a range of target substances in real-world samples.

Furthermore, the chapter discusses the principles of chemical sensing, including calorimetric methods, fluorescence, biosensor and electrochemical techniques, all of which utilize PtNPs for the selective identification of metal ions and pesticides. The benefits of using PtNPs as chemical sensors include their simplicity, speed, cost-effectiveness, and high sensitivity, making them valuable tools for monitoring contaminants in soil, water, air, and more.

Keywords: Metallic Nanoparticles, Pesticides, Heavy Metal Ions, Nanomaterials, Colorimetric Sensors, Electrochemical Sensors, Biological Sensors, Graphene Oxide, Quantum Dots, Biosensors.

Nomenclature

- CNTs : carbon nanotubes
- AuNPs : gold nanoparticles
- AgNPs : silver nanoparticles
- GO : graphene oxide
- HPAMAM : hyperbranched polyamide-amine
- DAC : dialdehyde cellulose
- s-SWCNTs : semiconducting single-walled carbon nanotube
- CFO : cobalt ferrite

- GQDs : graphene quantum dots
- PLAL : pulsed laser ablation in liquid
- LASiS : laser ablation synthesis in solution
- PVD : Physical Vapor Deposition
- EBE : electron beam evaporation
- PLD : pulsed laser deposition
- GCE : glassy carbon electrode
- CFP : carbon fiber paper electrode
- PANI : polyaniline
- LOD : limit of detection
- AA : ascorbic acid
- MOF : metal-organic framework
- TPA : terephthalaldehyde
- TAPB : 1,3,5-tris(4-aminophenyl)benzene

1. Introduction

Environmental sampling and analysis play a crucial role in addressing pollution and mitigating life-threatening situations resulting from ecological imbalances. These imbalances can stem from both natural processes and anthropogenic activities, including the improper disposal of waste into environmental reservoirs. The progression of science and technology has led to increased industrialization, which introduces effluents into ecosystems. Additionally, food production demands have prompted the agricultural sector to adopt chemical fertilizers and pesticides. The accumulation of these toxic substances poses significant risks to ecosystems, human health, and food chains, thereby disrupting ecological stability.

In a context where environmental pollution is escalating, nanomaterials emerge as a pivotal tool due to their superior electrical, optical, thermal, and catalytic properties, complemented by remarkable stability and sensitivity. These characteristics are particularly advantageous in the development of nanomaterial-based sensors and devices designed for monitoring environmental contaminants in air, water, and soil. A diverse array of nanomaterials including carbon nanotubes (CNTs), metallic nanoparticles, semiconducting nanoparticles, and quantum dots has been extensively employed for the sensitive and selective detection of toxic metal ions, harmful gases, pesticides, and hazardous industrial chemicals in a straightforward manner.

Pesticides as contaminants

Various classes of pesticides are introduced into the environment as contaminants, serving to prevent, destroy, repel or mitigate pest populations, which include insects, rodents, nematodes, fungi, weeds, and other forms of terrestrial or aquatic flora and fauna, as well as pathogenic bacteria and viruses. The principal categories of pesticides encompass organochlorines, organophosphates, carbamates, and neonicotinoids, among others.

Organochlorines are predominantly polychlorinated derivatives of cyclohexane and biphenyl compounds. Characterized by their low volatility and resistance to environmental degradation,

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these substances also demonstrate limited enzymatic breakdown, leading to the potential accumulation in fatty tissues.

Organophosphorus pesticides comprise various phosphates, thiophosphates, and dithiophosphates. These pesticides are relatively volatile and water-soluble, capable of undergoing enzymatic degradation, and do not exhibit significant bioaccumulation. Consequently, they pose a lower risk compared to organochlorines; however, they can still induce chronic toxicity at elevated exposure levels.

Carbamates are mainly esters derived from carbamic or thiocarbamic acids. These water-soluble pesticides exhibit negligible bioaccumulation and present lower toxicity.

Neonicotinoids, restructured from nicotine, are known for their enhanced bioefficacy. While they tend to have moderate to high toxicity, their adverse effects on humans are relatively minimal compared to their pronounced impact on non-target species, particularly pollinators such as honeybees. Additionally, a variety of other chemicals may also be employed directly as pesticides.

The primary contributors to the presence of metal ions and pesticides in the environment stem from industrial, agricultural, pharmaceutical, and domestic waste. Effluents from industrial and agricultural sources typically contain a variety of heavy metal ions, including chromium (Cr), cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb), arsenic (As), and zinc (Zn), along with various pesticides. The challenges posed by these contaminants have prompted scientists to focus on developing a cost-effective, sensitive, selective, and straightforward method for effectively monitoring these hazardous substances. Consequently, numerous studies have been conducted to identify strategies for mitigating these issues. Nanotechnology has emerged as a crucial player in addressing these challenges, as the unique properties of nanomaterials and nanoparticles provide innovative solutions to the problems associated with environmental exposure to metal ions and pesticides. The diminutive size, high surface-to-volume ratio, and unique optical characteristics of nanomaterials render them an effective tool for use as chemical sensors, facilitating the detection of metal ions and pesticides. This approach not only simplifies the sensing process but also enhances the probability and specificity of analyzing target substances at very low concentrations.

Metal ions as contaminants

Numerous heavy metal ions, including Hg, Cd^{2+}, Pb^{2+}, Ni^{2+}, and Cr^{3+}, are recognized for their high toxicity and carcinogenic properties. The presence of these metal ions in the environment poses a significant ecological challenge due to their harmful effects, even at minimal concentrations. The rapid expansion of industrial activities, mining, excessive fertilizer application and paper production has led to the direct or indirect discharge of waste water containing elevated levels of metal ions into the environment. In contrast to organic pollutants, which can be biodegraded, metal ions tend to accumulate within biological organisms. The adverse impacts of these metal ions have raised increasing concerns regarding public health and environmental stability. Therefore, it is crucial to eliminate or mitigate metal ion contamination in water to avert or lessen environmental pollution.

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2. NANOMATERIALS FOR CHEMICAL SENSOR FOR DETECTION OF METAL IONS AND PESTICIDES

Metallic nanoparticles

A diverse range of nanoparticles is available for the development of chemical sensors, particularly AuNPs [1] and AgNPs [2], which are extensively utilized in sensor fabrication due to their diminutive size and exceptional optical characteristics. Numerous studies indicate that PtNPs [3] also serves a significant function as a chemical sensor owing to its comparable properties to those of Au and Ag nanoparticles. These materials have been employed in the construction of colorimetric sensors, electrochemical sensors, and biological sensors [4,5].

Carbon based nanomaterials

The remarkable characteristics of carbon-based nanomaterials render them effective in identifying and addressing environmental pollutants. They have been evaluated for applications as sorbents, antimicrobial agents, sensors, and in renewable energy technologies and environmental protection strategies. Their notably exceptional attributes, such as high surface area, superior electrical and thermal conductivity, mechanical strength, and distinctive hybridization properties, position them as optimal candidates for detecting environmental contaminants, including heavy metal ions and pesticides.

In recent Liu et al. (2022) constructed a Hyperbranched polymers and cellulose were employed to functionalize the surface of graphene oxide (GO) to enhance the adsorption efficiency of heavy metal ions. Initially, hyperbranched polyamide-amine (HPAMAM) was utilized to modify GO through the creation of an amide bond between the carboxyl group of GO and the amino group of HPAMAM. This process augmented the number of active sites on the GO surface, thereby improving its affinity for heavy metal ions. Subsequently, dialdehyde cellulose (DAC), derived from the oxidation of microcrystalline cellulose, was grafted onto the GO/HPAMAM composite via a Schiff base reaction between the amino group of HPAMAM and the aldehyde group of DAC. Notably, the DAC modification resulted in the formation of micro/nano protrusions on the GO surface, which significantly increased the hydroxyl group density and the surface area available for interaction with heavy metal ions. The GO/HPAMAM/DAC adsorbent demonstrated impressive adsorption capabilities and remarkable stability through multiple cycles when it came to heavy metal ions. At a temperature of 298 K, it showed maximum adsorption capacities of 680.3 mg/g for Pb(II), 418.4 mg/g for Cd(II), and 280.1 mg/g for Cu(II), outperforming many previously reported adsorbents [6].

Semiconducting nanoparticles

Semiconducting nanoparticles, such as zinc oxide, quantum dots and cobalt ferrite nanoparticles, are proving to be highly effective tools in the detection of metal ions and pesticides. Their unique properties allow for modifications tailored for specific detection needs. These nanoparticles bring several advantages, including exceptional sensitivity and selectivity, along with the convenience of being easily integrated into various detection methods, whether optical or electrochemical.

Recent advancements in semiconducting single-walled carbon nanotube-based field effect

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transistors (s-SWCNT/FETs) highlight their impressive attributes, including high carrier mobility, an excellent on/off ratio, quasi-ballistic electron transport, as well as label-free detection with a real-time response. T. H. Vignesh Kumar et al. (2023) have developed cobalt ferrite (CFO) nanoparticles that are integrated with s-SWCNTs to connect the source and drain electrodes effectively. The resulting CFO/s-SWCNT/FET has been utilized for the non-enzymatic detection of carbaryl and carbofuran. As a sensing platform, the CFO/s-SWCNT hybrid film demonstrated remarkable sensitivity and selectivity, featuring a broad linear detection range from 10 to 100 fM. The lowest limits of detection were determined to be 0.11 fM for carbaryl and carbofuran 0.07 fM [7].

Quantum dots

Quantum dots have gained significant attention in the realm of fluorescence chemical sensors, thanks to their remarkable properties, including outstanding optical characteristics and unique quantum size effects. What's particularly fascinating is that their fluorescence capabilities can be fine-tuned by altering their structure, size, morphology, composition, doping, and surface modifications. Recently, these nanomaterials have emerged as top choices for detecting heavy metal ions and pesticide residues. The interaction between quantum dots and various analytes results in exceptional sensitivity and selectivity, while also minimizing equipment costs compared to traditional measurement techniques[8].

Hsieh et al. (2023) successfully synthesized nitrogen and boron-doped graphene quantum dots (GQDs). These GQDs were then utilized as sensing probes to detect pesticides and iron ions in aqueous solutions. The SPMA method demonstrates remarkable versatility for in-situ doping of various atoms within the graphitic structure of GQDs[9].

3. PLATINUM NANOPARTICLES AS CHEMICAL SENSOR FOR DETECTION OF METAL IONS AND PESTICIDES

Synthesis methods of PtNPs

Platinum nanoparticles can be created using a variety of techniques, which fall into three main categories: chemical, physical, and biological methods **(Fig.-1).** Chemical techniques typically involve reducing platinum precursors using agents like sodium borohydride. On the other hand, physical methods, such as laser ablation, involve the breakdown of bulk platinum into nanoparticles. Finally, biological techniques take advantage of microorganisms or plant extracts for both the reduction and stabilization processes.

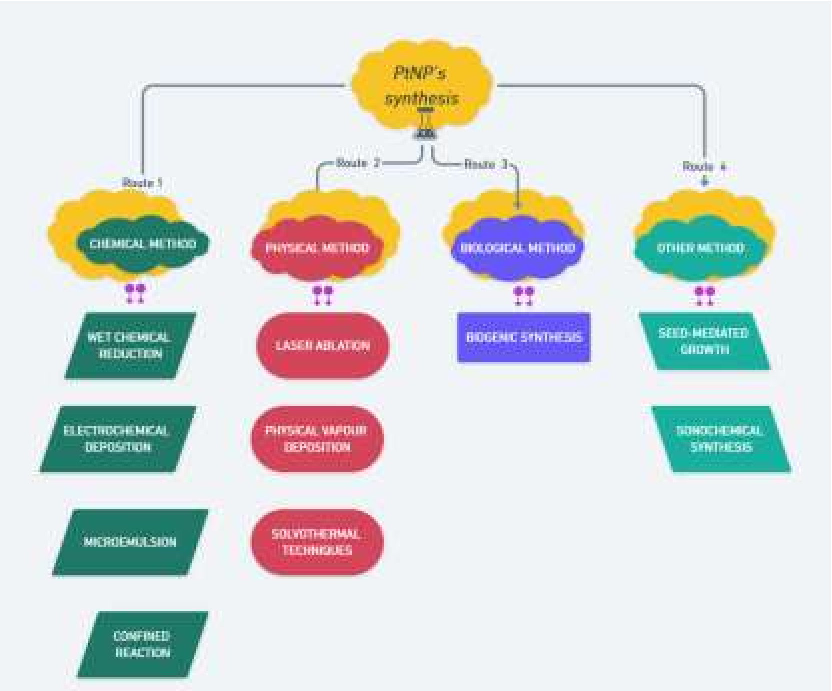

Fig. 1 – Synthesis route of PtNPs

A) Chemical Methods

Wet Chemical Reduction

This widely used technique involves reducing a platinum precursor, such as H_2PtCl_6, with a reducing agent like $NaBH_4$ in a solution. By tweaking parameters like reaction temperature, the concentration of the reducing agent, and the use of stabilizers, you can finely tune the size and shape of the nanoparticles produced[10].

Microemulsion

This technique involves a microemulsion system that combines oil, water, and surfactant to encapsulate the platinum precursor, aiding in the formation of nanoparticles[11].

Electrochemical Deposition

Electrochemical deposition is a widely used technique for creating PtNPs. This process entails the careful reduction of platinum ions from a solution onto a conductive substrate, enabling the production of nanoparticles with customizable size and shape. Various approaches, including pulse electrodeposition and two-step deposition, can be employed to refine the characteristics of the nanoparticles[12].

Confined Reaction

The confined reaction synthesis approach for producing PtNPs, focuses on generating these nanoparticles within a designated space, often utilizing porous materials or nanostructured frameworks. This technique effectively manages the nucleation and growth processes of PtNPs, resulting in a consistent particle size and enhanced dispersion. Unlike conventional methods,

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which may lead to variations in particle characteristics, this confinement strategy significantly shapes the ultimate morphology and properties of the PtNPs[13].

B) Physical Methods

Laser Ablation

Laser ablation is a widely used technique for producing PtNPs, especially through methods like pulsed laser ablation in liquid (PLAL) and laser ablation synthesis in solution (LASiS). This process involves directing a pulsed laser at a Pt target submerged in a liquid, resulting in the formation of a plasma plume that cools and condenses into nanoparticles[14].

Physical Vapor Deposition

Physical Vapor Deposition (PVD) techniques, including sputtering, electron beam evaporation (EBE), and pulsed laser deposition (PLD), are employed to create PtNPs. These processes involve the vaporization of platinum, followed by the deposition of the material onto a substrate, either directly or after the formation of nanoparticles in the vapor phase[15].

Solvothermal Techniques

Solvothermal synthesis is a powerful and effective technique for creating PtNPs by employing a solvent under carefully controlled temperature and pressure. This method allows for exact management of both particle size and shape. The process starts by dissolving platinum precursors in a solvent, then heating the mixture to a targeted temperature, which usually ranges from 100°C to 1000°C. Maintaining pressure during this stage is crucial for driving the reaction forward and ultimately yielding PtNPs[16].

C) Biological Methods

Biogenic Synthesis

Biological methods, often referred to as green synthesis or eco-friendly approaches, provide a sustainable means of producing PtNPs by harnessing the power of biological agents such as plants, fungi, and bacteria. These methods take advantage of the natural compounds within these organisms to convert platinum ions (Pt^{4+}) into PtNPs, effectively capping and stabilizing the resulting nanoparticles. This biogenic synthesis technique stands out for its cost-effectiveness, environmental friendliness, and non-toxic nature when compared to traditional chemical and physical synthesis methods [17].

D) Other Methods

Seed-mediated growth

Seed-mediated growth of PtNPs utilizes existing nanoparticles as "seeds" to spark and regulate the development of PtNPs. This technique offers detailed control over the size, shape, and composition of the nanoparticles[18].

Sonochemical Synthesis

The process of creating PtNPs through sonochemical synthesis harnesses the power of

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high-frequency ultrasound waves to trigger chemical reactions that yield these nanoparticles. This technique relies on acoustic cavitation, a phenomenon where microbubbles form, grow, and collapse in a liquid, generating extremely high pressure and temperature conditions locally. These extreme conditions play a crucial role in reducing platinum ions and facilitating the formation of PtNPs [19].

4. PROPERTIES OF PLATINUM NANOPARTICLES MAKING IT SUITABLE AS A CHEMICAL SENSOR

The effectiveness of PtNPs as catalysts is influenced by their composition, size, and shape. platinum is a rare and valuable metal, significant efforts have been devoted to enhancing the efficiency of these catalysts to minimize platinum usage. Factors such as chemical reactivity, inter-atomic bond distances, and electronic characteristics can markedly affect the properties of PtNPs. Additionally, their crystal structure, surface condition, and chemical composition can significantly alter how these nanoparticles facilitate electron transfer.

PtNPs have garnered considerable attention in the development of electrochemical sensors, thanks to their remarkable electronic and electrocatalytic properties. These include outstanding sensing and catalytic capabilities, low background current, solid stability, and chemical inertness. A promising approach to improve the electrochemical properties of these nanoparticles is to create electrodes based on platinum nanocomposites[20].

Fig. 2 - Application of PtNPs

5. DIFFERENT TECHNIQUES USED FOR CHEMICAL SENSING USING PtNPs: RECENT PROGRESS IN PESTICIDE DETERMINATION

Electrochemical Sensors Based on Nanomaterials

Electrochemical sensors that leverage PtNPs are designed to harness the unique catalytic and conductive characteristics of Pt for the detection and measurement of a wide range of analytes. These can include organic compounds, biological molecules and even environmental pollutants. The fabrication process typically involves depositing PtNPs onto a working electrode, like a glassy carbon electrode (GCE) or a modified carbon fiber paper electrode (CFP). In this setup, PtNPs serve as electrocatalysts, significantly speeding up the electrochemical reactions of the target analyte, which in turn enhances the signal output.

A new electrochemical sensor designed for detecting mercury ions (Hg(II)) has been created using a nanocomposite made of platinum, graphitic carbon nitride (g-C3N4), and polyaniline (PANI), according to a study by Mahmoudian et al.(2020) The sensor fabrication utilized a straightforward and cost-efficient synthesis method for the Pt/g-C3N4/PANI nanocomposite, which was then characterized through various techniques. Evaluation of the electrochemical properties revealed that the nanocomposite showed remarkable electrocatalytic activity for the reduction of Hg(II) ions. The resulting sensor provided a broad linear detection range from 1 to 500 nM and achieved a low limit of detection (LOD) of 0.014 nM. Notably, the sensor displayed strong selectivity for Hg(II) ions, maintaining its performance even when faced with other potentially interfering ions. The findings indicate that the Pt/g-C3N4/PANI nanocomposite holds significant promise for creating high-performance electrochemical sensors aimed at detecting Hg(II) ions in both environmental and industrial settings. This research underscores the potential of nanocomposites in advancing sensing technologies [21].

Ya ma et al. (2021) synthesized A layer of 2-methylimidazole zinc salt (ZIF-8) membrane is coated onto a glassy carbon electrode that has been enhanced with PtNPs using a reduction electrochemical method, resulting in the ZIF-8/PtNPs/GCE composite. This setup is then employed for the detection of ascorbic acid (AA). The presence of PtNPs on the GCE surface not only facilitates the nucleation and growth of the ZIF-8 membrane but also provides a synergistic effect that boosts conductivity. For ZIF-8 membrane, it can increase the active area of electrode and thus improve the electrochemical response of the sensor for AA[22]. This study effectively explains the working mechanism of functionalized PtNPs as electrochemical sensor.

In a modified pathway Size-tunable PtNPs was developed by Mazzotta et al. (2021) through a simple method in an aqueous medium without catalyst-poisoning reagents, are utilized here for the electrocatalytic detection of hydrogen peroxide. These PtNPs exhibit exceptional electrocatalytic properties and have shown promising results in the electroreduction of hydrogen peroxide, a well-established catalytic reaction involving nanostructured platinum materials. The study clearly demonstrates that smaller nanoparticles enhance the electrocatalytic performance. In amperometric detection of hydrogen peroxide at -0.1V, these nanoparticles achieve impressive results across a concentration range of 25-750 µM, with a detection limit of 10 µM[23].

Ru et al. (2022) introduced an innovative method for detecting arsenic in water by utilizing a combination of UiO-67 metal-organic framework (MOF), graphene oxide (GO), and PtNPs. The UiO-67 MOF was synthesized using biphenyl-4,4'-dicarboxylic acid (BPDC) as a ligand alongside $ZrCl_4$, resulting in a porous structure capable of adsorbing and concentrating arsenic. The addition of GO and PtNPs enhances the electrochemical properties of the sensor. Notably, this sensor demonstrated high sensitivity and selectivity for arsenic detection, achieving a limit of detection lower than the safety standards set by the World Health Organization (WHO). The study suggests that this new sensing platform could play a vital role in environmental monitoring and toxicological assessments. Additionally, they developed a method that is quick, simple, eco-friendly, and sensitive for arsenic detection in water. However, it is important to note that the testing so far has only been conducted on a limited range of environmental

samples, indicating that further testing is required to explore its effectiveness in various contexts [24].
Another approach by J. Hao et al. (2024) has been presented where they developed a novel electrochemical sensor using a composite of covalent organic frameworks (COFs) and PtNPs for the detection of ofloxacin (OFX) in water. The process began with the synthesis of the COF material through the condensation reaction of 1,3,5-tris(4-aminophenyl)benzene (TAPB) with terephthalaldehyde (TPA). Subsequently, PtNPs were integrated into this framework using in-situ reduction. The resulting TAPB-TPA-COFs/PtNPs composite was then applied to a glassy carbon electrode (GCE) via drip coating to form the working electrode (TAPB-TPA-COFs/PtNPs/GCE). Notably, the electrochemical performance of the TAPB-TPA-COFs/PtNPs/GCE exhibited a remarkable enhancement, resulting in a 3.2-fold increase in the electrochemical signal when analyzing 0.01 mM OFX, compared to the TAPB-TPA-COFs/GCE alone[25].

Optical Sensors Based on Nanomaterials

Optical sensors hold significant potential and offer a wide array of applications for the on-site detection of various analytes, including heavy metals and pesticides. When an analyte interacts with electromagnetic radiation, it causes specific changes in the optical properties—such as absorption, transmission, emission and lifetim that are unique to analyte. The principle behind these sensors relies on analyzing the optical signal's alterations before and after it interacts with the analytes.
In the case of nanoparticle-based sensors, notable changes in response occur due to target-induced aggregation or anti-aggregation of the nanoparticles. This leads to modifications in the nanoparticles' surface characteristics, resulting in variations in the optical responses before and after the analyte's interaction.

Colorimetric

Colorimetric sensor arrays exhibit unique colorimetric response patterns when interacting with various analytes, making them valuable tools for identifying analytes that share similar structures and properties through statistical analysis. However, many existing colorimetric sensor arrays rely on multiple receptors and sensing units, which can drive up both detection costs and complexity. To address this challenge, multichannel colorimetric sensor arrays, capable of capturing multiple signals from a single sensing receptor or reaction unit, are gaining renewed interest in research.
K. Somnet, et al. (2021) putting forward a plan to create an innovative, ready-to-use electrochemical sensor that features a screen-printed graphene paste electrode (SPGrE) enhanced with platinum nanoparticles and covered with a molecularly imprinted polymer (PtNPs@MIP). This development aims to provide a sensitive and cost-effective solution for the detection of paraquat (PQ) herbicide[26].
Towards this modern approach A straight forward multichannel colorimetric sensor array was developed by Li et al. (2022) to identify and detect pesticides, utilizing PtNPs as the sensing receptor. These Pt NPs effectively catalyze the direct oxidation of 3,3′,5,5′-tetramethylbenzidine (TMB), resulting in three significantly enhanced absorption peaks at 370

nm, 450 nm, and 650 nm. This provides three cross-reactive sensing elements for identification purposes. Each pesticide exhibited unique colorimetric responses and distinctive patterns, similar to fingerprints, due to the varying inhibition or enhancement effects on the catalytic activity of the PtNPs. Successful discrimination of five pesticides- dursban (DB), dimethoate (DM), 3-ketocarbofuran (3-KC), glyphosate (GLY), and malathion (MA), was achieved through principal component analysis and hierarchical cluster analysis [27].

Jiang et al. (2024) utilized the oxidase-like (OXD) activity of platinum-nickel nanoparticles (Pt-NiNPs) in conjunction with 3,3′,5,5′-tetramethylbenzidine (TMB) to create a dual-mode probe capable of colorimetric and photothermal detection of organophosphorus pesticides (OPs). The process involved the catalytic oxidation of TMB by the Pt-Ni NPs, resulting in a transition from a color. The dual-mode probe exhibited a linear response to chlorpyrifos, achieving detection limits of 1.2 ng/mL in colorimetric mode and 1.66 ng/mL in photothermal mode[28].

Fluorescence

Fluorescence sensors that utilize PtNPs are capable of identifying pesticides and heavy metals. They do this by showing variations in fluorescence when these substances attach to the nanoparticles. Such variations can manifest as either a decrease or increase in fluorescence, serving as an indicator of both the presence and concentration of the targeted analyte.

Chen, Jiamin, et al. (2020) developed a fluorescence biosensor utilizing the peroxidase-like activity of PtNPs for the swift detection of hypoxanthine (Hx), a crucial indicator of aquatic product freshness. The fluorescence intensity exhibited a linear correlation with Hx concentrations ranging from 8 to 2500 μM, achieving a remarkable detection limit of just 2.88 μM (S/N = 3). Additionally, the biosensor's outstanding selectivity, was fully utilize to measured Hx levels in fish, shrimp, and squid samples, yielding excellent recovery rates between 103.94% and 109.00%[29].

Recently Liu, Jie, et al. (2025) Created an innovative ratiometric fluorescent immunosensor for the detection of fenitrothion (FN) using chitosan-modified PtNPs (Ch-Pt NPs) as catalytic nanozymes. The new sensor outperforms traditional colorimetric ELISA by nearly 20 times in sensitivity, with a detection limit of just 0.48 ng/mL. It also shows impressive recovery rates between 80.0% and 108.3% in spiked samples. This ratiometric fluorescent immunosensor demonstrates exceptional performance, making it a promising tool for broad applications in pesticide monitoring[30].

Biosensors

PtNPs play a crucial role in the development of biosensors, utilized primarily in three significant ways. They serve as electrochemical catalysts to speed up enzyme reactions, act as sensor electrodes to improve electron transfer, and modify electrode surfaces to fix substrates and maintain enzyme activity. Over the past few decades, a variety of biosensors incorporating PtNPs have gained popularity. For instance, amperometric acetylcholinesterase biosensors are employed for pesticide detection, while electrochemical biosensors utilizing platinum nanotubes are effective for glucose detection. Additionally, graphene platinum-based hydrogen peroxide biosensors are widely used for detecting reactive oxygen species (ROS).

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A cutting-edge impedimetric biosensor has been created by Madianos, et al. (2018) for the detection of two widely used pesticides: acetamiprid and atrazine. This innovative sensor employs sputtering and e-beam lithography techniques to arrange PtNPs in a bridge-like formation between interdigitated electrodes (IDEs). The microwires formed from these PtNPs undergo chemical functionalization, enabling the covalent attachment of aptamers specific to the target analytes directly onto the sensor surfaces.
The study reveales that design of this biosensing platform enhances charge transfer through the microwire-bridged IDEs. When the target analytes bind to the attached aptamers, electron transfer is obstructed, leading to an increase in the impedance of the electrochemical cell. This synergy between PtNPs microwires and aptamers facilitates the sensitive and highly selective detection of acetamiprid, achieving a linear response range from 10 pM to 100 nM, with a limit of detection (LoD) [31]

6. FUTURE SCOPE AND CONCLUSION

In this review, we explored various approaches to synthesizing PtNPs, focusing particularly on physical, chemical, and biological methods. We provided an in-depth analysis of the biological techniques. We also discussed Different types of techniques where we use PtNPs as different type of sensors. Over the last decade, there has been significant advancement in creating monodispersed and well-defined structures of PtNPs.
In conclusion, PtNPs have proven to be essential in the realm of detection of metal ions and pesticides in environmental samples, providing unmatched sensitivity, selectivity, and adaptability. Their incorporation into sensing devices has enabled swift and precise identification of contaminants in water supplies, empowering proactive actions to protect public health and the environment. Yet, this is just the beginning. The potential for future developments in PtNPs-based sensing is extensive and exciting.
Further advancements in PtNPs synthesis techniques, sensor design, and detection methodologies hold the potential to revolutionize environmental samples quality monitoring. Pairing these advancements with cutting-edge technologies like artificial intelligence and the Internet of Things can enhance sensor functionality, allowing for real-time, autonomous assessments of metal ions and pesticides in environmental samples,. Moreover, fostering interdisciplinary partnerships among researchers, policymakers, and industry players is crucial for turning scientific discoveries into effective solutions that tackle the ongoing challenges posed Contamination detection in environmental samples.

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