



Sensitive Detection of Heavy metals by using Nano sensor in Environmental Samples

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ABSTRACT

One of the biggest problems facing mankind is the planned or unplanned discharge of harmful contaminants from many industrial sectors. In addition to being present in smaller amounts, most of these dangerous heavy metals also cause serious ecological problems. Therefore, the development of detection methods for the monitoring of these heavy metals is very important. Nanomaterial-based sensors have been used extensively in the detection of heavy metal ions. Recent developments in material science have revived this field and led to the emergence of precise nano sensors with a variety of designs and functions. Specifically, sensor production has employed semiconductors, noble metal nanoparticles, and porous nanomaterials in combination with analytical methods such as mass spectrometry, electrochemistry, colorimetry, surface-enhanced Raman scattering, and fluorescence. Recent developments in heavy metal ion sensors based on nanomaterials are reviewed in this study, with an emphasis on their analytical capabilities, uses, and difficulties.

Keywords: Heavy metal, Nanomaterial, Nano sensor, Detection mechanism.

INTRODUCTION

Heavy metals are defined as metals as well as metalloids having a density of 4 g/cm³, or five times more than that of water. They may also exist as elements, ions, or compounds. According to the United States Environmental Protection Agency (USEPA), As, Hg, Cu, Ni, Pb, and Cd are among the most dangerous contaminants.¹ Via the diet,

such heavy metals enter into the human beings and change the properties of soils, water sources, and plants.² Therefore, for ecological sustainability and health risk assessment, proper measurement of trace heavy metal ions in specimens of various substrates is important. Numerous attempts have been made to investigate quantitative techniques for toxic metal ion detection in order to accomplish this goal. The vital role of particular



metals, including iron, zinc, manganese, and copper in the proper ratios, has just come to light. Fortunately, lower interactions with such essential metals pose significant hazards to human health and the ecosystem.³ Ecological and healthcare professionals are getting more and more concerned with the quantity and type of contaminants. The accumulation of heavy metals in an individual's body has detrimental impacts on their health.⁴ Pollution is responsible for almost nine million deaths worldwide. These consequences are approximately three times greater than AIDS, TB, and malaria-related fatalities. Every facet of physical and mental health, including intelligence, is adversely impacted by contamination.⁵ For instance, Fe³⁺, which is essential for living, is a major player in a number of metabolic events. However, an excessive amount of Fe³⁺ ion accumulation may specifically cause cardiovascular disease, diabetes, and inflammation of the liver.

Furthermore, high mercury consumption can cause neurological problems, loss of hearing, and kidney damage in humans. Additionally, Pb²⁺, which comes from water supply lines and dissolves in water for consumption, adversely affects kid's neural and immunological systems and induces high blood pressure and lasting neurological disorders. Numerous techniques, such as, atomic emission spectroscopy (AES), inductively coupled plasma mass spectrometry (ICP-MS), ICP-AES, atomic absorption spectroscopy (AAS), chromatography methods etc. have been successfully used to identify trace amounts of heavy metal ions. The prolonged commitment, high expense, and complicated procedures of conventional technologies, however, restrict their ability to be used widely⁶⁻⁹ however, it is difficult to detect many metal ions at once. Thus, it is important to develop unique detectors for the quick, accurate, highly sensitive, cost-effective, and practical evaluation of various toxic ions.⁶

Table 1: Permissible Limit and impacts of different heavy metal ion¹³

Metals	WHO Limit a (mgL ⁻¹)	Sources	Impact on Human beings
Arsenic	0.05	Preservatives, Release of untreated effluents, Oxidation of pyrite (FeS) and arseno	Causes impacts on disorders of the cardiovascular and pulmonary systems, as well as the central and peripheral neurological systems
Cadmium	0.005	Paints, Electroplated parts, Batteries, Plastics, Synthetic rubber, Photographic	Lymphocytosis, microcytic hypochromic anaemia, high blood pressure, loss of weight, tiredness, and kidney damage
Lead	0.05	PVC pipes, Agriculture, Recycled PVC lead paints	Disrupts the barrier between the blood and the brain, which has been found to be an indicator of risk for Alzheimer's disease and other forms of dementia
Mercury	0.001	Combustion of coal, Solid waste incineration and Volcanic emissions	Minamata, lung capacity, kidneys, the epidermis, eyesight, gastrointestinal system, immunological system, and abnormal neurological functioning
Chromium	0.05	Leather industry, Tanning and Chrome plating industries	Embryotoxicity, mutagenicity, carcinogenicity, malignancies of the lung, skin irritation, teratogenicity, Teratogenicity,

Over the course of the last twenty years, there has been a growth in the demand for nanotechnology sensors on an international level. Nano sensors have been effectively used in equipment for diagnosis in medicine as well as other applications. It may be used at many different levels and is also used in the layout of building projects. This can help environmentalists develop more economical, successful, and sensitive nanoparticles for monitoring various contaminants.¹⁰ Because of their wide surface area, great enzymatic efficacy, high degree of responsiveness, and outstanding

capacity to adsorb, nanomaterial-based detectors, in particular, are showing enormous potential in identifying the presence of heavy metals.¹ The drawbacks of conventional analytical techniques for detection are made up for by nano sensor devices due to their affordable price, excellent effectiveness, numerous functions, mobility, specificity, and responsiveness.¹¹ This article discusses the most recent developments in Induced Coupled Plasma-Mass Spectrometer, colorimetric, Surface-enhanced Raman scattering, electrochemistry, and fluorescence-based nanostructured detectors

for to measure the presence of heavy metals.¹² The combination of sensors into microfluidic chips considered an important step towards the application of detectors to real-world samples is highlighted in this paper's discussion of nano sensors as well as their detecting approaches and progress.

Nano sensors

In order to identify the characteristics of materials in a specific ecosystem at the nano scale to molecular level, nanotechnology sensors serve as measuring systems that rely on the distinctive features of nanoparticles.¹⁴ Such sensor devices, which may be either small or large, use the nanoparticles built in as identification components to find alterations at the nano scale.¹¹ A Nano sensor is a device that senses with a minimum of a single dimension and a maximum of 100 nm and is employed to collect data for evaluation and acquire details at the nano scale. Some examples of nanostructured materials used in the production of nano sensors include nanoscale wires, tiny carbon nanotubes, and nanoparticle of metal oxide and nano films. For use in chemo-resistive monitoring, nanostructures made of graphene are currently undergoing substantial study. Because of their small dimensions and large surface-volume ratio, nanoparticles provide substantial benefits over conventional thick films for detection.¹⁰ The primary function of a Nano sensor is the atomic-scale data and signal collection that it performs, which gives it great detection sensitivity.¹⁵

Nanomaterial used in synthesis of Nano sensor Carbon

Carbon nanotubes can be classified as either single-walled or multiwall, and they are presumably tubular, rolled-up sheets of graphene.¹⁶ These cylindrical structures consist of sp^2 carbon units.¹⁷ These carbon nanotubes have great electron mobility, good conductive qualities, considerable mechanical strength, and anisotropic electrical conductivity. Additionally, because carbon nanotubes are composed entirely of carbon, they are environmentally advantageous due to their great stability and minimal toxicity. These carbon nanotubes are regarded as crucial components of smart nanomaterials and cutting-edge nanotechnology because of their remarkably excellent thermal, mechanical, optical, electrical, and magnetic capabilities. The biomedical field,

photovoltaic cells, sensors, optical devices, drug delivery, ecological assessment, devices for storing electricity, and catalytic processes are only a few of the sectors that could make use of them.¹⁸ Due to their great mechanical strength, excellent electrical conductivity, significant thermal conductivity, and huge surface area, carbon nanotubes are frequently used in Nano-enabled sensors. Increasing the sensitivity of glass-carbon electrodes for electrochemical monitoring is one recent application of these nanomaterials.¹⁹ Carbon nanotubes are being used in the pressure sensor, bio, and photo sensors.¹⁶

Polymeric Nanomaterials and Bio-Nanomaterial's based nano sensor

Excellent thermal conductivity, mechanical, catalytic in nature, physical, and electrical capabilities are possessed by bio-nanomaterials and polymeric nanomaterials. Therefore, these kinds of nanostructures can be employed to develop electrochemical sensors and very specific and sensitive Nano biological sensors. Bio-nanomaterials-based sensors: a lot of sensors have been developed through integrating the catalytic action of macromolecules with the special properties of nanoparticles. By self-organization, the molecules can combine with biological materials and produce appropriate nanostructures by technique self-assembled monolayers. Polymer-based nanomaterials: To detect gaseous and liquid harmful substances as well as contaminants in foods, polymeric nanoparticles have been integrated with a variety of sensing methods. Graphene, carbon nanotubes, metals, metal oxide nanoparticles, etc., can all be integrated to enhance the electrochemical measuring capabilities of polymer-based nanomaterials.²⁰

Nano diamonds based Nano sensor

Nano diamonds originated as individual particles of diamond with a dimension of 4–5 nm.²¹ The diamond phase; durability to severe conditions; chemical stability; good biocompatibility; configurable surfaces; and excellent electric resistance and conductivity to heat. Because of these physical characteristics, nano diamonds can be used in a wide range of industries, including the delivery of drugs biological applications, and catalytic processes. Fluorescent Nano diamonds have attracted a lot of interest in the past ten years.²² As

coupling agents for surface functionalisation with numerous functional groups, the nano diamonds surface can be modified by many types of oxygen-containing groups, including the carboxyl group, the hydroxyl group, ketones, and the ethers. In contrast to the typical carbon-based nanomaterials, these special qualities provide outstanding qualities that make them a far better option for sewage treatment.²³

Fullerenes

Amorphous carbon, diamond, and graphite are the well-known allotropes of carbon, each with unique characteristics. The physical characteristics of carbon are significantly impacted by the allotropic form.¹⁸ Due to their conductivity, charge transport, separation of charged particles, and photo physical characteristics, fullerenes have drawn a lot of interest in the sensor field. Because C60 has 60 electrons in its molecular structure, the electron-withdrawing groups can attack it nucleophilic ally. Also, a maximum of six electron can be reversibly accepted by the C60 molecule itself.²³ The kinds of graphene used in sensors are also quite significant. Functionalised graphene is one kind of graphene that shows a high level of electrochemical reactivity to electron transfer processes. Graphene is ideal for detecting bound chemicals that are impacted by electrical current due to this unique feature. The general physical properties of the graphene materials used in Nano sensors are an essential factor.²⁴

Graphene

The well-known carbon-based substance graphene is typically created by mechanically polishing graphite. Graphene oxide, which contains phenol, the hydroxyl group, carboxylic, and epoxide groups, is often made using Hummer's technique. Active sites can be introduced, and surface hydrophilicity can be increased by doping the graphene's carbon matrix with heteroatoms (such as nitrogen, boron, and phosphorus). The ability of graphene or its derivatives to fix different nanoparticles through surface treatment is one of their benefits; this characteristic has been used to increase the signal strength and sensitiveness of metal ion sensors.²⁵ Specifically, surface functionalization and size modification of graphene sheets can be used to control the fluorescence property of graphene. Graphene oxide shows visible-near-infrared fluorescence because of

the tiny sp^2 carbon domains buried in the SP^3 matrix. The atomic and electronic structures of graphene oxide are highly heterogeneous, indicating that fluorescence in GO is caused by the recombination of electron-hole pairs in localised electronic modes that can originate from a variety of different configurations. Its optical qualities can be improved for use in chemical sensors by controlling its size to within a few nanometres.²⁵

Nafion-G hybrid electrochemical detectors demonstrated high sensitivity for metallic ion detection. Due to their many appealing characteristics, including ultra-sensitivity, label-free, and immediate reaction time on the same level with or superior to that associated with traditional techniques, field-effect transistor detectors made from nanomaterials, such as nanowires, nanotubes, and nanoparticles, have proved to be an accurate sensing system for recognising the presence of biological and chemical contaminants.²⁶ The use of diethyldithiocarbamate doped graphene quantum dots in resonance light scattering sensors for the sensitive detection of heavy metals like lead is being considered as a green method of metal complex nanoparticles. In this kind of ultra-trace level Pb^{2+} determination, it can therefore be utilised as the resonance light scattering sensor for detection of metals.²⁷

Functionalized derived material

The affinity for binding of functionalised nanostructures for the target is greater. This kind of technology is suitable to recognise harmful substances for several ecological remediation processes. As well as that, functionalised fluorescent nanoparticles are suitable for a number of sensing applications because of their unique interaction with the samples (such as cadmium, lead, mercury, copper, etc.), large surface area, significant loading ability, and pore structure. Specific surface encapsulation of nanoparticles, which also retains their luminescent properties, significantly improves target-specific detection capacity.²⁸ Cd^{2+} , Pb^{2+} and Cu^{2+} ions are the harmful metal ions that can be absorbed by amino-functionalized $Fe_3O_4@SiO_2$ magnetic nanomaterials. Furthermore, $Fe_3O_4@SiO_2$ nanoparticles (Nps) with thiol functionalization have been developed in order to sequester Pb^{2+} and Hg^{2+} from water samples.²⁹ Many quantum dots, such as CdSe, InP, CdTe, GaAs, and others, are used as photonic metal detectors in industry because

of their low detection limit and high quantum yield. Because of its remarkable capacity to adjust the wavelength of the light in the visible spectrum region (380–740 nm) by varying its diameter, CdTe is a highly useful polycrystalline nanoparticle and is employed as an optical sensor. CdTe quantum dots have been used extensively in recent years as metal ion detectors and fluorescent biological indicators. These are also utilized in optoelectronic fabrication and clinical imaging probes. CdTe quantum dots have been selected as a good alternative for a wide range of easily available organic fluorophores because of their high quantum yield (35–70%) and photochemical activity.³⁰ Nor-Flu, a norbornene-based monomer produced from fluorescein, and its polymer, PNor-Flu. These substances exhibit remarkable sensitivity and selectivity in the detection of copper ions. Detection is more accurate and efficient, which makes it a very useful tool for environmental monitoring.³¹

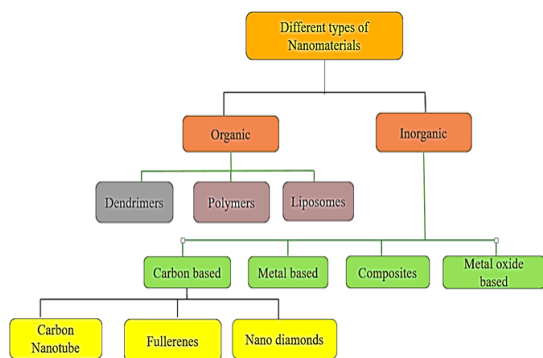


Fig. 1. Different types of nanomaterial used for synthesis of various nano sensor

Manufacturing of Nano sensor

Nanotechnology is the process that produces different materials or nanomaterials (NMs) at the microscale for a number of applications. Numerous orders of magnitude separate the dimensions at which the manufacturing process is conducted. Although terms such as "nano fabrication" and "nano manufacturing" are sometimes used collectively, "nano fabrication" mostly refers to a nanotechnology implemented in funded research projects, whereas "nano manufacturing" corresponds to the development of materials for economic gain. There are three primary categories into which a variety of nanofabrication approaches belong. Outline of three distinct approaches to nanoparticle and nano manufacturing for nano sensors: top-down, bottom-up, and molecular assembly. These three approaches are briefly described as follows:³²

Bottom-up approach

The "bottom-up" strategy is the most appropriate one.³² With this method, tiny parts-even molecules-are assembled or joined to create the final structure. Chemical or physical vapor deposition, contact the printing process, etching, assembling and combining, and sealing are examples of common bottom-up techniques.³² The bottom-up fabrication develops the comparatively consistent dimensions and shape of nanoparticles.³³ by reducing the metal salt with an appropriate reducing and stabilizing agent. Employing a bottom-up technique, carbon-based nanomaterials and nanotubes made from them can be used to nano manufacture an apparatus that can perform on one individual cell.³²

Top-down approach

The final shape is achieved by gradually trimming a huge block of stone or wood. This method is top-down. This method is employed in nanofabrication when a sizable block of substance is selected and gradually eliminated through milling until the desired shape is achieved. The two phases of the top-down method are pattern transfer and nanolithography. The top-down strategy is now the most well-liked and extensively applied strategy in the nano manufacturing sector.³²

The basic synthesis route for Nano sensors

X-ray lithography: A more sophisticated form of optical lithography that uses shorter wavelengths is called X-ray lithography. This technique defines the pattern using a unique kind of mask with various local X-ray absorption regions. An X-ray-sensitive substance known as a resist, which has been previously put on a substrate (often a silicon wafer), replicates this pattern. Depending on the chemical makeup of the oppose, the X-ray that passes through its structure may produce bond breakage for positive resists or cross-linked for negative resists. A variety of the chemical composition of the object to bond breakage may occur (for positive resists). According to its structure, either the exposed region resist will dissolve and develop a structure, or vice versa, once the entire object has been subjected to and immersed in a particular solvent. The resist's other component will remain complete. It demonstrates how nano patterns are made on the base material using X-ray lithography.³²

Focused ion beam lithography: This technique produces an opening of different thickness on the wafer without the need for a resist by controlling the amount of ion by altering the wafer's position. For a more effective result, heavy-ion species like gallium and gold can also be employed in this lithography. An opening with an inverse Gaussian form is created when a light source is run across the wafer. The opening gets narrower, sharper, becoming increasingly V-shaped as its strength increases. Complex forms can also be produced via numerous cycles.³²

Electron beam lithography: In electron beam lithography, only one wafer pixel undergoes exposure at a time using a precisely concentrated Gaussian circular light that rotates with the wafer. With the help of the etching and coating processes, the light beam can construct a very complex nanostructure by forming the design that is needed on the wafer. Despite being incredibly popular and inexpensive, this technique's biggest flaw is how much time it takes. To make this method more relevant, researchers are working to advance the technology.³²

Types of Nano sensor

Heavy metal ion detection by different Nano sensors and the detection limits of metal ions are very promising for sustainable environmental health. Various types of nano sensor is shown in Fig. 2 and their analytical parameters and their limit of different Nano sensors for metal analysis is given in Table 2 and Figure 7.

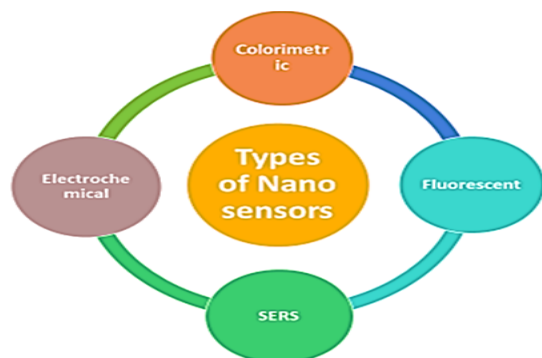


Fig. 2. Different types of Nano sensor which are used for detection of various heavy metals in Environmental samples
Colorimetric

The chemical analyte molecule is readily, quickly, and selectively determined using the

colorimetric method. Based on how the substance being measured reacts with the colorimetric sensor, colorimetric they are tiny in size and have a high surface-volume ratio; nanoparticles provide substantial benefits over conventional bulky sheets for detection.¹⁰ The identifying of small quantities of metal has recently been the subject of numerous novel detecting technologies utilizing colorimetric, electrochemistry, surface-enhanced Raman scattering, and fluorescence. MS and SERS, which have ultrahigh sensitivities, are two of these techniques that offer precise molecular knowledge. The selected metal ions' variations can be easily and simply observed because of the use of colorimetric and fluorescence sensors. Additionally, because of their quick and unique reactions to diverse metal ions, electrochemical detectors are suited for the continuous sensing of several metalloids. Nanotechnology, which includes noble metal nanoparticles, permeable nanomaterial, semiconductors, etc., has been extensively employed in the building of sensing devices which efforts to increase the metal-ion monitors' specificity and responsiveness.⁶

Measures color quantitatively. Colorimetric sensor assessments are perfect for immediately detecting and evaluating since they are adaptable, easy to understand, and don't need particular preparation or pre-treatment. Such types of sensors are used for detecting analytes like DNA from infections, microorganisms, chemical compounds, and inorganic elements. However, one of the biggest limitations is attaining an extremely low level of identification, which is sometimes unable to identify the analyte of interest because it only exists in traces. PNP-based colorimetric detectors exhibited great effectiveness, sensibility, and accuracy in these characteristics. Compared to commonly employ natural colorants, the intended component is easier to identify and is detected more consistently.³⁴⁻³⁵ Due to their exceptional visual, heating, physical, biological, and electrical capabilities, copper, gold, and silver nanoparticles are frequently used in LSPR-based sensing technologies. Heavy metal ion sensing has made considerable use of gold nanoparticles (AuNPs), which exhibit strong chemical durability and autoxidation.³⁶ The colorimetric identification approach has been used for monitoring a number of heavy metals, including mercury, lead, copper, and

arsenic. The colorimetric analysis approach is quick and easy shown by Fig. 3. But it needs preliminary

concentration to identify metal traces because its LOD is so high.¹

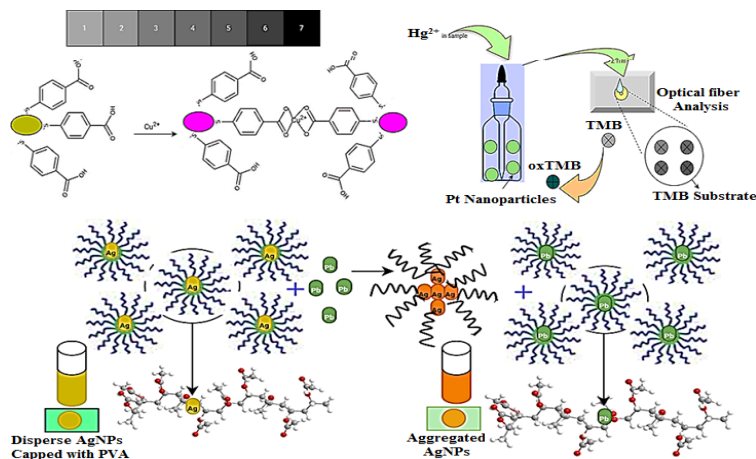


Fig. 3. Detection mechanism for different heavy metals by Colorimetric sensors

Fluorescent sensors

When constructing fluorescent detectors for recognizing the presence of heavy metals, scientists focused on the Fluorescence resonance energy transfer procedure. Fluorescence sensing relies on analyte-induced modifications of the physical-chemical properties of fluorophores, such as their duration of action, magnitude, and anisotropy, that are connected with the processes of charge or transfer of energy. FRET happens when an energy donor and an energy acceptor communicate with one another as dipoles with a $1/d^6$ distance between them dependence.³⁷⁻³⁸ Because of the economical accessibility of toolboxes, widely recognized labeling strategies, and concise form that minimizes potential steric interference, natural colorant are typically used as fluorescent substances in detectors. Natural dyes still exhibit light bleaching as well as a constrained activation spectrum. Because of their distinct features, inorganic semiconductors such as metallic clusters, carbon dots and oxides of graphene had become alternate fluorophores. Chemiluminescent detectors have generated attention as an addition to standard fluorescence sensors based on Fluorescence resonance energy transfer and Nanoparticle Surface Energy Transfer sensors for the sensing of metal ions.³⁹ The construction of the sensor array can be made simpler by using chemiluminescent resonant energy transfer sensors, which activate the donor's luminescence through a chemical method rather than a light source that is outside.

Along with the transfer of energy

technologies, for metal ion detection fluorescence sensors also been designed using the electron transfer process. Multiple techniques, such as the Dexter interaction, intermolecular photo induced transfer of electron, and interfacial electron transfer, are used to move electrons shown in Fig. 4. Electron transmission is excellent at a gap of no more than one nm, and its rate constant progressively decreases with increasing distance from the nucleus. A QD-based sensor was created for detecting mercury (Hg^{2+}) and silver (Ag^{+}) simultaneously by using the electron transfer process. 12 Fluorescence sensors are nowadays being used using a variety of fluorescent nanomaterial, such as noble metal Nano clusters, up conversion NPs (UCNPs), QDs, MOFs, etc.⁴⁰ Fluorescent nanomaterial-based sensors have great responsiveness, specificity, and durability because of the modifications made to ligands or compounds that are particular to toxic metal ions.

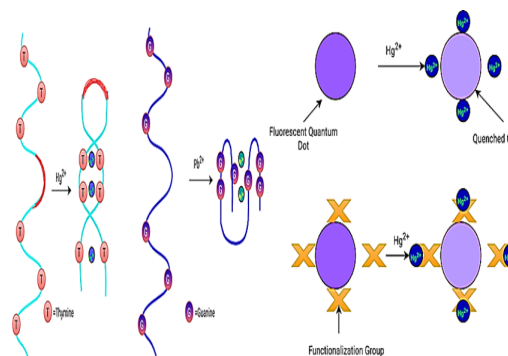


Fig. 4. Detection mechanism for different heavy metals by Fluorescent sensors

Surface-enhanced Raman scattering (SERS)

Especially, SERS displays exceptionally excellent sensitivity due to the fact that the analyte-induced SERS signals can be amplified using the potent electromagnetic waves produced by plasmon nanoparticles. Silver and gold surfaces with dense "hotspots" are among the frequently employed plasmonic nanoparticles; they effectively intensify electromagnetic radiation when exposed to laser light.⁶ A few studies have documented the identification of heavy metals using SERS sensors, despite the fact that they have been widely employed for biochemical sensing as well as clinical diagnostics.⁴¹⁻⁴⁴ SERS is not able to directly identify heavy metal ions; however, it can offer the spectrum fingerprint patterns of metabolites which is shown in Fig. 5. By combining an organic binder into plasmon nanoparticles with an excellent sensitivity for metallic ions, this particular issue can be overcome.¹² Gold and silver substrates with dense "hotspots" are among the frequently employed plasmonic nanoparticles; they effectively intensify electromagnetic fields when exposed to laser light. The analytical agents with vibrating inherent SERS impulses might be obtained directly for direct Surface-enhanced Raman scattering biosensors. The study of transition metals present in inorganic, metal organic, or organometallic compounds is thus appropriate for direct this type of biosensors. For instance, using a variety of silver nanomaterial-based Surface-enhanced Raman scattering bases, the spectra of arsenic (As^{3+} & As^{5+}) have been effectively obtained.⁶

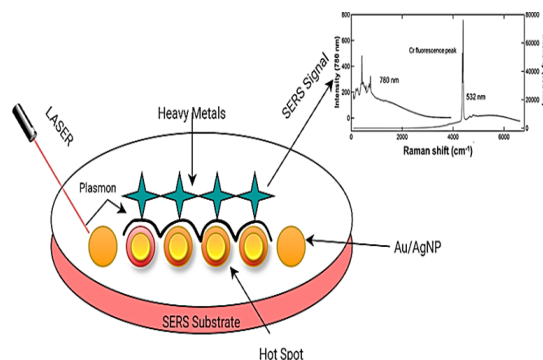


Fig. 5. Detection mechanism for different heavy metals by SERS

Electrochemical sensor

From microscopic particles to massive macromolecules, these small devices employ the special characteristics of nanomaterials to identify and record modifications in material. Integrating nanomaterials and electrochemical sensor arrays has become an effective technique for identifying heavy metal ions in the last few years. The components utilised to alter the electrode surface significantly affect the efficacy of the detecting mechanisms shown by Fig. 6, which is related to machinery, optical signals, or EC routes. Of all sensor systems, nanomaterials and carbon-derived alternatives, such as biochar, are excellent choices for electrode assembly because of their remarkable electrochemical qualities. Because of its special qualities, metal-organic frameworks have developed as a viable material for wastewater treatment. These characteristics include the capacity to modify the framework for certain pollutants, a sizable surface area for adsorption, and well-defined pores enabling size-selective absorption.⁴⁵

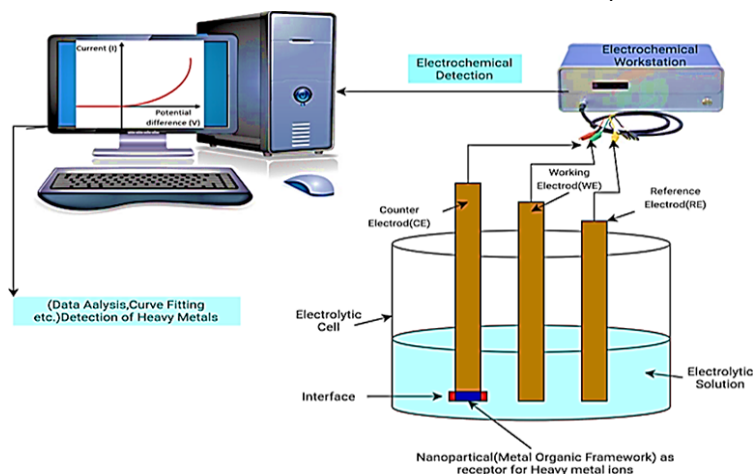


Fig. 6. Detection mechanism for different heavy metals by electrochemical sensor

Table 2: Different analytical parameters of different Nano sensors for metal analysis

Type of Nano sensors	Metal ions	Material	Mechanism	Observation	Features	LOD	Reference
Colorimetric	Hg	Silica nanoparticles that are mesoporous	Due to its strong affinity for sulphur, Hg(II) may react with solid S2 to break down linear dithioacetal bonds, producing new Hg(S-R)2 and causing the eventual release of cargo. The colour shift that results from etching silver-coated gold Nano bipyramids is used to identify mercury.	The sensing range of the Nano sensor is 29.9 a.u/μM.	Fundamental, unaided vision	60 pM	3 ,5,46,47
Nano sensor	Hg	Nanoparticles bipyramids of gold (Au) covered in silver	The Nano sensors allow for detecting with the naked eye. APP-AuNPs more easily than other elements.	The method removes the requirement for complicated procedures and reduces time.		0.8 μM	3 ,5, 46,47
Surface Plasmon resonance	Pd	AuThe SPR was eliminated because Pd (II) assembled	Epicatechin-coated AgNPs caused a hyper chromic change in the metal. When there are other interfering metallic ions present, silver nanoparticles may identify Pb ²⁺ selectively.	Determination of structures of molecules in actuality, with excellent sensitivity		4.23 μM	3 ,5 , 46,47
Magnetic fluorescent based Nano sensor	Hg	Magnetic fluorescent composites functionalised with carboxymethyl chitosan	Fluorescence of the Nano sensor is quenched.	The Nano sensor shows enhanced sensitivity and specificity for mercury (Hg ²⁺) ions.	Mobile, quick, and economical	9.1 ×10 ⁻⁸ mol/L	3 ,5,46,47
Electro chemical sensor	Cd ²⁺ , Pb ²⁺ , Cu ²⁺	Nano sheets of thermally reduced graphene oxide and Fc-NH2-UiO-66	The highest voltage increases in synchrony with the amount of heavy metals.	Indicated as an excellent tool for simultaneously identifying many heavy metal ions.	Compact, quick, and economical	8.5 nM, 0.6 nM, 0.8 nM	3 ,5,46,47

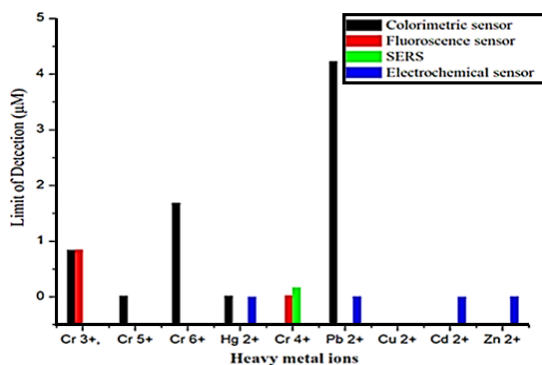


Fig. 7. Detection limits of different Nano sensors for various heavy metal ions

Advantages of Nano sensors

The detector's time of response is an indication of the quickness with which it reacts to an alteration in information. Especially for Nano sensors employed in areas like quality of air and toxic metal assessment, this feature is very important. To evaluate their harmful effects and environmental sedimentation, major and hazardous metals, including lead(II), cadmium(II), mercury(II), and arsenic(III), must be detected. Due to its ease of use, affordability, and mobility, electrolytic stripping evaluation has traditionally served as the foundation methodology for the fabrication of toxic metal detectors. Recently, a wide variety of enhanced screen-printed electrodes have come to light as viable possibilities for manufacturing toxic metal Nano sensors. In the past few years, Nano sensing systems developed through studies have become commercially accessible. The present developments are really encouraging, even if an extensive amount of work still needs to be done to make the various Nano sensors readily accessible in the marketplace. Researchers are looking to integrate Nano sensing innovations with adaptable, compact systems in the scientific community as well. The functionality of the compact systems frequently met the requirements for detection at the operational level. Screen-printed electrodes, field-effect transistors internet-based and continuous monitoring chips, colorimetric sections, and lateral-flow tests can all be classified as significant compact nano sensor technologies. A distinct benefit of the nano sensors is their ability to exhibit high degrees of detecting sensibility or accuracy. A nano sensor's responsiveness is calculated as the size or strength of the observed pulse per unit of concentration of analyte. A sensor's specificity refers to its capacity to

determine the amount of a substance in the presence of additional conflicting chemicals. Furthermore, a useful nano sensor must be capable of picking out a substance of want among complicated mediums. A specific metallic element, for instance, from an actual sample that also includes additional metal ions. Numerous nanotechnology-based sensors have been discovered and reported with the significant selective trait.¹⁵

Limitations of Nano sensor

There is always a concern that nanomaterial-based sensors may not be affordable because the fabrication methods and character development devices employed throughout the manufacturing and implementation of nanomaterials are relatively expensive. For the manufacture and promotion of innovative point-of-care equipment, such as those for bacterial identification and toxic metal ion estimation, almost all of the manufacturing sector and corporations still favor conventional cellulose, fiber, and carbon-based technologies. The research and development of the forthcoming generation of toxic metal detectors with affordable fabrication, a simple-to-use interface, and field-usable results are of significant value. Extremely precise and specific colorimetric analysis is possibly an excellent option for the present in terms of device expenses to meet such next-generational aims.

The majority of the traditional techniques for pollution monitoring operate on the basis of self-standardization and calibration testing. A large number of existing recognized or discovered nano sensors do not always entirely encompass this capability. Additionally, there will always be significant uncertainty regarding the validity of the overall test outcome if the nano sensors are calibrated using just a few reference testing specimens. In actuality, the majority of nano sensors (or the detecting portion of the nano sensor) are constructed with recyclable materials in mind. In regular analytical applications, the inter assay accuracy of a number of such sensing electrodes, chips, and testing kits is generally ignored. Nano sensors are devices that are typically made as recyclable electrodes, kits, or sheets. This is essential to establish standards that have been thoroughly examined and verified for dumping after employing such sensors. There isn't any way to dispose of the sensor components with regular trash. Since this is the case, providers must

make an effort to educate consumers regarding the right way to dispose of nano sensors at the point of their release for business purposes.¹⁵

CONCLUSION

In many different domains of application, particularly for ensuring ecological and health safety, the sensitivity and specific identification of heavy metal ions are extremely important. In the last ten years, a lot of work has gone into realizing excellent electrical detection specificity and sensitivity for heavy metal ions. Nanomaterial was recently included in the manufacturing process of detectors to increase their accuracy and specificity in the detection of certain contaminants. In comparison to more traditional approaches like Atomic Absorption Spectroscopy (AAS), Atomic Emission Spectroscopy (AES), Induced Coupling Plasma Mass Spectroscopy (ICP-MS), or devices that employ organic fluorescent pigments, modified nanoparticle-based nano sensors are efficient and have a number of benefits.

In conclusion, this article provides a brief overview of sophisticated nanomaterial-based detectors for recognizing the presence of toxic metal ions, in addition to colorimetric, electrochemistry, SERS, and fluorescent analytical techniques. To achieve excellent specificity and consistency in heavy metal-ion detectors, it is essential to choose appropriate biomolecules as transmitters that uniquely recognize the desired metal ions. The most relevant nano-sensors have made it possible to quickly, easily, extremely sensitively, and inexpensively detect distinct metallic ions in various substances.

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Conflict of Interest

We, the authors of this research article declare no conflict of interest.

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