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Functional Nanomaterials in Catalysis and Sensing Applications

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Abstract: *The role of nanomaterials is very important due to the fact that they possess large surface area to volume ratio, ease of functionalization, fast electron transfer kinetics, catalytic activity and biocompatibility and also selectivity and specificity. With the advent of nanotechnology, its application incatalysis and sensing is entering to a new era for the design of innovative sensors that can sense low level concentration of analyte by portable sensor device which was hardly possible earlier. Sensors have fascinated much consideration in the recent time because of potential applications of these devices in the clinical diagnosis, pharmaceuticals, environmental monitoring and food processing industries etc. The main focus of present paper is the investigations of metal nanomaterials such as silver, gold, platinum, palladium and carbon-based nanomaterials to develop efficient catalyst and sensors for early and accurate detection of biomolecules, drugs and pollutants. These materials showed enormous potential to use as active material for catalysis and sensing applications.*

Keywords: Role of Nanomaterials

I. Introduction

Study of nanomaterials for the catalysis and sensing has fascinated continuous attention. The synthesisand construction of novel nanomaterials are one of the current and most focused research in the field of chemical engineering and chemistry. Nanomaterials are defined as materials with at least one external dimension in the size ranges from approximately 1-100 nanometers[1]. It is extensively supposed that once size of catalyst decreases up to the nanometer, the interactions among catalyst and reactant increases dramatically[2].Variety of nanomaterials ranging from metallic nanoparticles (gold and silver nanoparticles), graphene and their derivatives, transition metal dichalcogenides, semiconductor nanoparticles (quantum dots) to polymeric, liposomal, dendrimers, and solid lipid nanoparticles have been explored broadly for sensing applications.[3-5]

Developing a range of sensors has important impact on daily life. Fundamental issues towards the incorporation of sensing platform include the demand for low costs and have potential for real time measurement, mainly for point-of-care applications. With significant achievements in the nanoscience and nanotechnology, nanomaterials-based sensing signal amplifications have enormous potential for improving both selectivity and sensitivity of sensors. The growing demand for cost-effective, simple, rapid, and portable screen in methods for the qualitative and quantitative determination of analytes relevant to medical research, clinical diagnosis, environment and food safety monitoring, and bio security investigation has been accelerated the development of nanomaterials-based sensors.

Further Composite nanomaterials are the materials composed from two or more constituents with significant various physical or chemical properties. When they combined together, produce a new material with different properties from the individual components. There are several reports available in literature to explore the usefulness of composite/hybrid nanomaterials to tune the properties as well as to reduce the cost[6-8].

Currently, gold nanoparticles (AuNPs) decorated inorganic semiconductor composites have enhanced conductivity and catalytic activity for development of highly selective and sensitive sensors. In fact, these materials exhibit extensively better catalytic and electrochemical behaviours than nanomaterials alone, thus suggest the potential applications of nanocomposites in development of stable, low-cost and novel sensors. The inclusion of metal nanoparticles into transition metal dichalcogenides (TMDCs) e.g. Molybdenum disulphide (MoS_2), Tungsten disulfide (WS_2) resulted in the better catalytic activity, increased sensitivity and surface-enhanced Raman scattering (SERS), in sensing [3,5,9]. For the development of nanotechnology, the role of nanomaterials is very important due to the fact that they exhibits remarkable properties such as high catalytic efficiency, high surface area, reaction activity, extraordinary electrical and thermal conductivities, magnetic behaviour, good biocompatibility, ease of functionalization, high degree of selectivity and specificity and strong adsorption ability and are ideal for the development of highly efficient sensors[10,11].

II. Nanomaterials as Catalyst

Metal nanomaterials exhibit excellent catalytic properties and are different from their bulk counterparts since the catalytic property originates due to their quantum-size dimensions. Enzyme-mimetic nanomaterials are exposed as ultimate and significant tools for the detection of various analytes owing to their high stability, controllable structure, low cost, tunable catalytic activity and easy preparation[12]. First discovered nanomaterial, Fe_3O_4 magnetic nanoparticle (MNPs) exhibits surprising enzyme like catalytic activity[13].Zero-dimensional nanomaterials such as AuNPs[14], cerium oxide[15], $ZnFe_2O_4$ MNPs[16], carbon nanodots[17], one-dimension nanomaterials such as carbon nanotube[18], V_2O_5 nanowires[19], two dimensions (2D) nanomaterials such as graphene oxide[20], have been explored as peroxidase mimics in catalyzing H_2O_2 -mediated color reaction and further used in the bioassays and medical diagnostic.

Ivanova et al developedPt-decorated Boron Nitride Nanosheets as artificial nanozymes for the detection of dopamine. These Nanocomposites possess peroxidase like catalytic activity and accelerates oxidation of peroxidase substrate 3,3',5,5'-tetramethylbenzidine (TMB) in presence of hydrogen peroxide (H_2O_2). Oxidation of TMB gives an efficient platform for colorimetric detection of essential biomolecules i.e. dopamine. The increased amounts of the dopamine slowly inhibit catalytic activity of nanocomposites for the oxidation of TMB by H_2O_2. Present study contributes to knowledge of nanomaterials with excellent enzyme like catalytic activity for dopamine sensing [21].

Design of metal nanomaterials based electrochemical sensors,reduces over potential of the different analytically significant reactions. Nanomaterials can also alter the irreversibility of several chemical reactions. Osaka and coworkers proposed a highselective and sensitive electrochemical device used for selective detection of dopamine in the presence of ascorbic acid which is based on the catalytic activity of synthesized gold nanoparticles falling over-potential of ascorbic acid[22].

III. Nanomaterials Based Sensors

The selectivity of a sensor mostly relies on the specificity of interaction between receptors and analytes. However, the sensitivity, stability, selectivity, response time and the detection limit of sensors strongly depends on the physicochemical properties of the transducer, which can be improved by the combination of nanomaterials as an interface between transducer and receptors. Metal nanostructures are ranging from noble to transition elements. Among metal nanostructures, noble metal nanostructures of well tunable in their size and shape along with unique properties like extraordinarily catalytic activities and optical properties have been extensively utilized in recent years, in various sensing applications. The uniqueness of optical, chemical and physical properties of the nanomaterials ascertain them very appropriate for developing new devices related to sensing. There are number of literature reported on nanomaterials based sensors. Electrochemical method was developed for detection of hydrogen peroxide (H_2O_2) with palladium nanoparticles-graphene nanosheets (PdNPGNs)modified electrode. Ultrafine palladium nanoparticles were homogeneously modified on the graphene based glassy carbon electrode (GCE). Additionally, the electrochemical sensor existing excellent reproducibility and stability shows potential in practical analysis[23].N. F. Atta et al. worked on the electro-sensing of morphine based on the gold nanoparticles modified graphite paste electrode (GPE) by DPV and CV methods. Morphine drug is potent analgesic usually advised to peoples suffering from pain. Electrochemical study of morphine showed an anodic peak response in buffer at pH 2 conforming to oxidation of the tertiary amine into the pseudo morphine as chief product. Electrodeposited gold nanoparticles modified electrode is used for study of oxidation behaviour of morphine. Due to the high electro catalytic effect and larger surface area of gold nanoparticles, the oxidation potential shifted towards the less positive potential region. Further the electrochemical sensing of morphine is performed at pH 7.4 by DPV in BR buffer and real sample (human urine and spiked) [24].

Sensitive and selective electrochemical sensor for glucose detection based on the anodized CuO nanowires (NW) with porous copper foam (CF) has been developed. System showed excellent electro-catalytic activity and high sensitivity towards glucose detection due to high surface area of 3-dimensional porous copper foam. CuO-NWs/CF electrode shows good repeatability high selectivity, stability and reproducibility towards glucose detection. Proposed glucose sensor is also applied in human serum for practical applications and results obtained show good agreement with commercially available glucose sensor[25].

Transition Metal Dichalcogenides (TMDCs) such as MoS_2, WS_2, $MoSe_2$, and WSe_2show excellent catalytic, electronic, and optical behaviour. Lan et al. proposed a highly sensitive colorimetric sensor for assay of label-free DNA based on ultrathin transition-metal dichalcogenide nanosheet. Hybridization chain reaction is introduced for enhanced detection sensitivity. This label−free sensor exhibited excellent selectivity as well as low limit of detection [26].

Recently, ongoing works have been devoted for development of highly sensitive sensors for detection of hazardous molecules. In the view of human health and environmental protection, a lot of efforts have been proposed to rapid detection of pollutants using nanomaterials. Several efforts have been performed to design the portable sensors for measuring pollutants like heavy metals in the environment. Inclusion of nanostructures and nanomaterials into the sensors leads to considerable enhancement in the performance of designed devices in the terms of selectivity, sensitivity, multiplexed detection capability and portability.[27]

IV. Conclusion and Perspective

This article, summarize variety of nanomaterials exhibiting extraordinary catalytic and sensing properties and progress on various methods with cost effective and greater stability. The growing demand for cost-effective, simple, rapid, and portable screen in methods for the qualitative and quantitative determination of analytes relevant to medical research, clinical diagnosis, environment and food safety monitoring, and biosecurity investigation has been accelerated the development of nanomaterials-based sensors. Metal nanomaterials are different from their bulk counterparts since the catalytic property originates due to their quantum-size dimensions. The artificial enzymes or catalytically active nanomaterials show numerous advantages over the natural enzymes, like controlled synthesis, high stability against harsh conditions, tunability in catalytic activities, low cost etc. Nanomaterials are a good substitution candidate of the natural enzymes and act as a catalyst in catalysis and sensing.

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