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A CHAPTER ON ROLE OF NANOTECHNOLOGY IN SENSOR FABRICATION

Abstract

The number of hazardous pollutants in the environment is increasing, which results in more air pollution and serious health risks in everyday life. To avoid these issues, it is necessary to precisely detect and identify these unstable and dangerous gases in the environment. Thus, by comprehending the concept of sensing, researchers have been able to fabricate nanosensors using various nanoparticles and composites to increase both the specificity and sensitivity of gases and humidity detection. The incorporation of nanomaterials has rendered it possible for scientists to apply novel methods in sensors for the transfer of signals to increase their efficiency and sensitivity. As a result of their unique material, magnetic, chemical, physical, and electrical characteristics, nanoparticles like metal oxides, graphene, ionic liquids, conductive polymeric materials, carbon nanotube materials, and particles of quantum dots have been extensively used to develop sensing devices with increased precision and sensitivity. For their improved efficiency, fast monitoring, and application in detecting hazardous gases, all nanoparticles and novel composites employed as sensors need to be synthesized and fabricated. The application of nanomaterials in the fabrication of novel sensing materials is also covered in this chapter. These characteristics of gas sensors can all be significantly enhanced by a reduction in the size of the particles in nanometers, metal doping, and innovations in device fabrication. The shape and spacing size of the electrodes, among the essential properties of the sensor, have significant effects on the gas sensing properties. The most significant features that influence the ability to detect gases are structural, surface, and type of semiconductor. These characteristics can all be modified by

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fabrication techniques. Therefore, the objective of this chapter is to provide an overview of the many sensing techniques as well as their fabrication, operation, and advancements in technology.

Keywords: Sensor Fabrication, Nanoparticles, Pollutants, fabrication techniques

I. INTRODUCTION

The worldwide population explosion emphasizes more than ever the significance of nanotechnology for all societies. In developing nations, the expansion of manufacturing industries is considered vital for achieving development goals. A growing population requires the advancement of novel technologies for better comfort. Researchers from various fields of applied sciences, including chemistry, physics, biology, medical sciences, and engineering, have investigated the multidisciplinary field of nanotechnology. Nanotechnology is the study, manipulation, and characterization of substances with precise atomic dimensions. Materials having a size of 100 nanometers or less are considered nanomaterials. Large-scale industrialization and automation are continually contaminating the environment, which might lead to big disasters in a short period of time. As a result, a clean and healthy environment is a requirement of modern civilization. There is an increasing demand for monitoring hazardous gases including CO, CO_2, NO_X, SO_2, and NH_3 as there is concern over the environment and human health. In our daily lives, the usage of NH_3 is easily found in ice cream plants, wineries and breweries, petrochemical facilities, fruit juice, vegetable juice, and soft drink processing facilities. Monitoring NH_3 by means of breath analyzers is very important and will be helpful for people suffering from lung and renal diseases. Detection of ammonia gas is highly demanded since ammonia is both a commonly used gas in various industrial sectors and a highly toxic and corrosive agent that can threaten human health and the environment. CO_2 increases global warming in the environment. Hence, the detection of CO_2 is also important so that sequestration of carbon can be done to address the issue of global warming. NO_2 monitoring is important in understanding environmental assessment, planning transportation, and making decisions regarding air pollution management. Furthermore, scientists and researchers are interested in monitoring these dangerous chemicals. Gas sensors are used in a variety of applications, including safety (detecting explosive gases), fermentation control in the food sector, diagnostics, environmental protection, patient monitoring, and detection of flammable gases. Current research activities have shifted to a greater emphasis on the creation of a dependable and low-cost sensor employing various novel materials and technologies.

Materials such as semiconductor metal oxides, carbonaceous allotropes, carbon polymer composites, and conducting polymers can be utilized to make different gas sensors. Among them, metal oxide semiconductor-based gas sensors have lately been used due to their numerous benefits, including low cost, high stability, and quick reaction time. Different metal oxide semiconductor-based gas sensors, such as MoO_3, SnO_2, SnO, Al_2O_3, Bi_2O_3, TiO_2, In_2O_3, CuO, Cu_2O, and Fe_2O_3, have been reported to function as gas sensors for detecting various gases [1,2,3,4,5,6]. Metal oxide-based gas sensors have several properties such as sensitivity, stability, adsorption ability, and so on. Many materials appear to be suited for some of these traits, but only a handful found suitable. Doping metal or metal oxides with other metal oxide surfaces can enhance their gas-sensing properties. A space charge layer is created when two metal oxide semiconductor materials with distinct band gaps are intimately connected within a heterojunction device. In this layer, free electrons in one material with higher Fermi energy could move into the contiguous material spontaneously due to the demand of band alignment arrangement until their Fermi levels reach at a similar energy, resulting in the formation of a depletion layer at the p-n hetero junction due to the recombination of holes and electrons. These hetero junctions formed at the interface, accelerate the transport of electrons which enhances the adsorption of oxygen at the surface due to the abundant oxygen vacancies formed and provides the new active sites for sensing.

The effectiveness of catalytic reactions with measured gas involvement at the surface of the gas-sensing material determines the conductivity response in many gas sensors. As a result, controlling the catalytic activity of gas sensor materials is one of the most often utilized methods for improving gas sensor performance [7]. Many metal oxide sensors like SnO_2 show poor sensitivity without catalysts [8]. In comparison to the great success mentioned above, the design of high-performance different oxide-oxide semiconductor gas sensors and doped oxide gas sensors is still very much in the early stages of investigation. In particular, no one has reported the LPG/ammonia sensing performance of CuO/In_2O_3, $CuBi_2O_4/MoO_3$ nanocomposite surfaces. This is of great importance to studying enhanced properties of transition metal oxides and their applications as humidity and gas sensors. It will also help to sense various properties accurately and play an important role in modern society. Assessment of gases present in the environment is important to keep the environment stable and healthy for human health.

II. SYNTHESIS OF NANOPARTICLES

1. **Sol-gel Techniques:** The main three methods for synthesizing sol-gel solutions include gel formation in a colloidal powdered form, hydrolysis, and polymer condensation of alkoxide or nitrate precursors, followed by drying and then aging under ambient air [9]. Nanomaterials synthesized via the sol-gel technique can be used as ceramics, optoelectronic devices, memory components, and biosensors due to several advantages, including enhanced bonding among the substrate and the top coating, excellent coating, operation at higher temperatures, reduced weight, simplicity, and affordability [10]. The sol-gel technique can control the size and morphology of the samples, due to which it can fabricate a wide range of organic, inorganic, and hybrid materials [11]. Dubey et al. synthesized the amorphous phase of SiO_2 nanoparticles using the sol-gel technique and reported that the nanoparticles have a hygroscopic nature and an average size of 25 nm studied via FTIR and TEM characterization and have found applications in industrial sectors [12]. Owens et al. reported that a wide range of materials like silica-based, phosphate-based, metal-based, calcium phosphate-based, organic, and inorganic-based materials can be synthesized using the sol-gel technique and found to have controllable structure and particle size and can be used in biomedical sectors [13].

2. **Chemical Vapor Deposition:** Chemical vapor deposition (CVD) is a fabrication method that is mainly employed for synthesizing bulk, powder, and composite nano materials. The method is frequently employed in the field of semiconductors to fabricate thin films. It comprises the deposition of thin films on the surface as a result of chemical processes. Different materials, including plasma, photons, ions, lasers, and hot filaments, have been employed to modify the deposition rate. The thin films that are deposited using this method appear to be conformal, have a high degree of purity, and deposit at a rapid rate. The primary drawback of this method is the utilization of toxic and explosive precursors, such as $Ni(CO)_4$ and B_2H_6, respectively. The synthesized materials can be used to purify metals and in optoelectronics [14]. Liu et al. fabricated nanorods of ZnO using plasma-enhanced CVD without using catalysts and reported the nanorods showed PL spectra at 386 nm and intensity and peaks shifted at higher annealing temperatures at 400 °C [15]. Wang et al. fabricated nanoflakes of MoS_2 using the CVD method and reported that the nanoflakes fabricated from CVD showed higher crystallinity than MoS_2 fabricated from other techniques [16].

3. **Spray Pyrolysis:** Spray pyrolysis is an increasingly common technique in industrial sectors for producing extremely fine particles since it is affordable and highly flexible. The four basic steps in spray pyrolysis are drop formation using precursors, reduction of drop size owing to evaporation, creation of oxides from precursors, and synthesis of solid particles. It is less expensive than others because this technique can work at atmospheric pressure [17].

4. **Bio-Synthesis:** Ren et al. synthesised nanoparticles of silver metal using biosynthesis techniques and studied their antibacterial, catalytic, electrical, and optical properties. They reported that the silver nanoparticles were synthesised using green raw materials such as apple pomace extract and $AgNO_3$ in a volume ratio of 4:1 and found particle sizes in the range of 10–20 nm [18].

5. **Spinning Disc Reactor:** With a substantially higher amount of product per unit processing time, Mohammadi et al. controlled the fabrication of TiO_2 nanoparticles in a spinning disc reactor (SDR) [19].

6. **Mechanical Milling:** This method reduces the particle size while milling the powder with high energy. Nanograins, nanocomposites, nanomaterials, nano-quasi-crystalline materials, and nanoalloys are the major materials of this method. In this technique, cold welding increases particle size while fracture produces finely structured particles with smaller particle size. This method is used to synthesize high yields of nanoalloys such nickel, magnesium, aluminum, copper, carbides, and different oxides [20].

7. **Sputtering:** Sputtering is commonly used methods for the deposition of thin films. In this technique, high-energy particles are used to knock out atoms from the cathode end of the materials by means of collision. This technique easily controls the thickness of the thin film by adjusting the parameters and deposition rate [21]. Verma et al. synthesized nanoparticles of CuO via sputtering and reported that the nanoparticles exhibit a monoclinic phase and increased crystallite size at higher sputtering pressure. They also reported that the nanoparticle fabricated at higher sputtering pressure exhibited lower optical band gap [22]. Wang et al. synthesized thin films of Au/SnO_2:NiO employing sputtering of SnO_2:NiO targets on Au nanoparticles and reported NO_2 gas sensing at 500 °C. They reported that the sensor showed the highest response of 185 at 5 ppm NO_2 and had better stability [23].

8. **Thermal Decomposition:** By employing iron as a precursor, acetylacetonate as a solvent, and polyethylene oxide as a surfactant, Chin et al. synthesised magnetite nanoparticles using the thermal decomposition method. They reported that altering the surfactant, precursor, and reaction time may influence the size and structure of magnetite nanoparticles [24]. Salavati-Niasari et al. synthesised nanoparticles of copper and copper(I) oxide via thermal decomposition technique and reported that the nanoparticles have an average diameter of 10 nm and an energy band gap of 2.4 eV [25].

9. **Laser Ablation:** Nanoparticles of all types, such as metal oxides, nanocarbons, doped-metal oxides, nanowires, tiny dots of semiconductor, and core shell particles, can be synthesised via the laser ablation technique. By using this technique, species that have been laser-vaporized in a background gas proliferate and form nanoparticles. It is

convenient for fabricating nanomaterials in the nanosized range (10 nm) by quenching vapor at an incredibly fast rate [26]. Ultrapure nanoparticles can be synthesised via this well-known technique, and key elements like the laser pulse, the ablation medium, the laser's focusing situation, and the plasma plume can be used to regulate various aspects like size, structure, and distribution. The laser pulse's width, repetition rate, time duration, wavelength, and laser fluence are all influencing factors. A range of other parameters, including the liquid environment, the liquid media, the types of gas, the growth rate, and the pressure, can also affect the size of the nano particles. The colloidal particle size can be tailored by changing the laser's wavelength between 1064 and 355 nm, and higher wavelengths have greater efficiency [27].

III. APPLICATION OF NANOPARTICLES

1. **Industries:** Numerous nanoparticles, including silicon dioxide, titanium oxide, nickel oxide, iron oxide, magnesium oxide, copper oxide, aluminum oxide, and zinc oxide, as well as carbon-based nanomaterials, have been used in oil and gas refineries for a variety of objectives, including cementing, drilling fluid, and well stimulation. The incorporation of nanoparticles has enhanced a number of the attributes of these areas, including cementing, stability of foam, filtering rate, wellbore stability, and oil recovery [28].

2. **Renewable Energy:** Renewable energy has experienced rapid attention due to widespread applications like wind power, tidal energy, solar photovoltaics, and biomass, which can contribute about 17% of the world's total energy. Biomass is an important resource used for the production of electricity, but it requires more technological development [29]. Vinayan et al. synthesized palladium nanoparticles with nitrogen-doped graphene decorations and investigated their application as hydrogen storage in renewable energy. They reported that kinetic control and nitrogen doping contributed to the development of palladium nanoparticles. At 25 °C and 2 MPa pressure, the synthesized Pd/N-G exhibited a hydrogen storage capacity of 1.9 wt.%. Additionally, they reported that the synthesized nanoparticles exhibited exceptional acidic medium stability [30].

3. **Food:** Nanoparticles play a vital role in maintaining the quality of food in our daily lives. Active nanotechnology (like medicine distribution) and nano-systems (like robots) have replaced the first-generation passive nanoparticles. While food remains in its early stages, nanoparticles are increasingly being employed as carriers for antimicrobial agents needed in the food industry to prevent bacterial degradation of the quality of food [31]. Simbine et al. published a review article on the potential benefits of silver nanoparticles in the food sector. They stated that Ag nanoparticles may be created utilizing biosynthesis and discovered its use as an antibacterial agent. By employing antimicrobial nanoparticles, they are also employed to improve the duration of storage of food constituents [32]. In a review article, Milincic et al. examine the practical application of polyphenol nanoparticles in the food sector. They stated that polyphenols were appropriate candidates because they were employed as an anti-cancer, antibacterial, and antioxidant element but had some limitations, including poor solubility and being less stable. By enhancing their physicochemical and operational characteristics, they reported that these polyphenol nanoparticles aid in the storage of food ingredients [33].

4. **Medical Field:** The nanomaterials play a vital role in medical fields like drug and gene delivery, fluorescent biological labels, detection of proteins, tissue engineering, tumor destruction, DNA probing, detection of pathogens, improving MRI contrast, and can also be used as separators and purifiers of biological molecules and cells. Nanoparticles like silver are used as antimicrobial agents; titania is used in filters for bactericidal purposes; and platinum nanoparticles are used as anti-toxic elements [34]. Brede et al. reported a review of the application for the treatment of kidney diseases. Diseases like renovascular hypertension, acute renal failure, hemodialysis, renal transplant, reperfusion injury, imaging, medical treatment of metastatic diseases, and invasive surgical treatment can be easily diagnosed using nanoparticles. The nanoparticles can also be used to minimize kidney tumors using the RFA technique [35].

5. **Catalysis:** The application of catalysis plays an important role across a wide range of technologies, including those related to the environment, chemicals, and energy. Boutonnet et al. reported a review article on the synthesis of nanomaterials of metal, metal oxides, and metal-doped oxides using microemulsions and studied their application as catalysis [36]. The metal nanoparticles can be synthesised from biological sources, including microorganisms, bacteria, and different extracts of plants. Trees seem to be the most suitable among these living organisms, and they may synthesize nanoparticles on a commercial level. Microorganisms constitute nanoparticles at a higher rate during the synthesis process, while plants synthesize them at a more consistent rate. Gold nanoparticles were synthesised by Aromal et al. employing fenugreek as a reduction agent. They reported that the synthesised nanomaterials were used in catalysis by transforming 4-nitrophenol to 4-aminophenol by employing an excessive amount of $NaBH_4$ [37].

6. **Electrical Devices:** The nanoparticles were found to be potential materials for device fabrication, like batteries, optoelectrical, and magnetic storage devices, due to various characteristics like electrical, magnetic, optical, and morphology. The nanomaterials are used to fabricate memory elements and electrical devices. The devices like transducers and actuators can be fabricated using ferroelectric oxides like $BaTiO_3$, $Pb(Zr, Ti)O_3$, and $(Ba, Sr)TiO_3$. The materials TiO_2 and conducting polymers are used to fabricate photovoltaic solar cells [38]. If the development of these materials is based on atomic comprehension, there is a great deal of potential for designing novel electrical and chemically reactive instruments. The essential sizes of the layers of the sensors can be reduced by decreasing the transducer, potentially to the size of the sensing device [39]. Tasyarek et al. synthesised nanoparticles of nickel-deposited strontium titanate nano cubes and investigated their temperature-dependent characteristics. According to their findings, the ideality factor diminished from 2.30 to 1.02 and the barrier height rose from 0.27 eV to 0.80 eV as the temperature increased from 80 K to 400 K. The metal-deposited STO was found to be an important component employed for the manufacturing of temperature-based electrical appliances and sensors [40].

7. **Gas and Humidity Sensors:** In the advancement of sensors, nanomaterials play a number of significant functions. The perfect sensing device will initially be as tiny as possible and the least intrusive. It will definitely take nanotechnology methods such as those used in the IT sector to combine these processes into an instrument less than 1 mm^2. The second function of nanotechnology is to optimize the layout of the sensor's components to be as exact and precise as possible, minimizing the size of the sensing

device, reducing the surface-to-volume ratio, and achieving maximum sensitivity. Therefore, it is projected that new nanotechnology will make it possible to develop more specific, smaller, and inexpensive sensing devices with an infinite number of applications. It involves assessing the hygiene of drinking water, measuring pollution in the environment, determining the quality of food, and monitoring human health. Additionally, advancements may be employed to improve security, protection, and hospitals that are personalized to the patient's needs.

8. **Cosmetics:** Nanoparticles have been found to be promising in a variety of cosmetic goods, including deodorant products, detergent, dental floss, conditioner, moisturizer, sun screen cream, face wash, lipstick, blush, eyeliner, nail polish, scents, and others [41]. In several cosmetic items, such as shampoos and moisturizers, nano emulsions are frequently employed [42]. In a two-phase framework with nano particles that range in size from 50 to 100 nm distributed in an exterior phase, nano emulsions mix conventional cosmetic components involving fluids, oils, and detergents [43]. Because of the nanoparticle size, nano-emulsions are clear and agreeable to the touch; other formulation techniques have not yet been able to duplicate their texture and rheological characteristics [44].

9. **Wastewater treatment:** Metal oxide nanoparticles (MNPs) provide enormous potential as an economical, environmentally friendly, and water management approach. Zero valent metal nanoparticles exhibiting various electrical, optical, physical, catalytic, and magnetic characteristics are used as water management systems. The highest negative reduction potential of the zerovalent zinc nano particles makes them appropriate for wastewater applications [45].

IV. NANO PARTICLES AS SENSORS

Owing to their ability to monitor health and the environment in real-time, gas sensors made of transition metal surfaces have received a lot of interest. These sensing devices primarily rely on flexible sensors that experience mechanical deformations during use. Researchers are motivated to develop the most durable and flexible sensors due to the applications of gas sensors in many areas, such as homeland security, defense, routine monitoring of the environment and human health, and so on. Due to their excellent properties such as high surface-to-volume ratio, configurable band gap, and low power consumption, two-dimensional surfaces-based flexible sensors are being investigated for gas detection recently. Bhardwaj et al. fabricated the transition metal oxide-based NO_2 sensor by solve-combustion route and reported a maximum response of 60 mV towards 100 ppm NO_2 for Fe_2O_3-SnO_2 sensors having a fast response and recovery time [46]. The most important is the ability to operate at room temperature, which is not easily attainable in other gas-sensing materials. Sharma et al. designed an ammonia sensor of Ni-Co hydroxide/oxide at room temperature synthesized by an economical and wet chemical method [47]. Singh et al. fabricated an LPG sensor of ZnO/SnO_2 by a simple hydrothermal route and reported the sensitivity and sensor response of 3.78 and 276.51 respectively for 2.0 vol% of LPG concentration at room temperature [48]. Kabure et al. fabricated an LPG sensor of CeO_2-CuO synthesized by the microwave-assisted sol-gel method and reported a maximum response of 57.09% for a sensor operated at 275 °C and 24 ppm LPG concentration [49]. Zhou et al. reported the high performance of graphene-embedded transition metal surfaces gas sensors and studied the adsorption of small gas molecules (O_2, CO, NO_2, and NH_3) on pristine and various transition metal-embedded graphene samples [50]. Even though extensive research has been carried out nationally and internationally on gas sensors, how to enhance the response, selectivity, sensitivity, and performance of gas sensors using tailored surfaces with low-cost approaches has not been well explored. In various commercial and domestic areas, sensors are required to quickly detect hazardous and inflammable compounds. Numerous applications require devices that can track and recognize numerous gases and chemicals. A specific example is environmental surveillance, which includes identifying the presence of hazardous or other dangerous gases that may result from leakage. The four primary gases, CO_2, CH_4, chlorofluorocarbons, and oxides of nitrogen, are majorly responsible for global warming. Therefore, the fabrication of devices that detect these gases and monitor their level of concentration in the environment is required. Chemical sensors developed with nanomaterials can offer very sensitive and affordable portable equipment for in-situ chemical monitoring in space and terrestrial applications. The recommended gas sensors may also be helpful in the medical industry.

V. CURRENT STATUS AND FUTURE ASPECTS

In the field of medical care, there is an immense demand for quick, dependable, and affordable technologies that can identify, observe, and diagnose biological compounds and infections. The examination of contaminants in the environment, the identification of microorganisms that cause food poisoning, and the possible threat of biological warfare all reflect this desire. One of the key technological and educational problems of the twenty-first century is the design of biochemical and practical sensors. In order to address objectives in a range of disciplines, such as healthcare diagnosis, drug development, and detection of pathogens, the foreseeable future of sensing technologies demands substantial improvements in sensitivity and selectivity. The development of medical science has been largely dependent on advances in diagnostic technology. It provides a deep understanding for researchers and doctors to know about the diseases and viruses associated with enzymes, genetic disorders, and other health issues. However, a lot of the standard tests that are now in use are laborious, call for significant amounts of sample material, and are susceptible to false outcomes, either positive or negative. In order to observe the variety of nanomaterials, there is a requirement for the fabrication of sensing devices that are quick, reliable, and affordable. The advancement of sensors was actually made possible by nanotechnology. The total system has improved in speed, competence, expenditure, and accessibility. The utilization of nanoparticles and nanotechnology, such as hybrid nanomaterials with numerous operations, enzyme-immobilizing nanoparticles, and quantum dots, has considerably improved the transmission processes. Considering its multifaceted possibilities, the future of technology makes a compelling case for this versatile, flexible, and speedy identification technology. In order to improve overall operations and make them quicker, simpler, and more efficient, these materials are currently being taken into greater consideration for the fusion of chemical and biological sensors. The use of these substances to identify numerous significant routes and governing procedures has been encouraged by the development of nanotechnology and research. Sensor fabrication has developed to be more flexible, reliable, and responsive as a result of the rapid advancement as well as the intensity of nanotechnology investigation. Due to the enormous technological demand for quick, accurate, and affordable sensing devices in vital human endeavors like medical care, genetic analysis, production of food and beverages, chemical manufacturing, surveillance of the environment, security, and privacy, sensor technology has developed significantly. It is incredible how widely nanomaterials are being used in disciplines as diverse as electronic components, biochemical and healthcare products, polyethylene materials, optoelectronic devices, dispersions, and cosmetics.

VI. CONCLUSION

The objective of this chapter is to develop new approaches that have the potential to substantially advance the field of sensor fabrication. The recent development of nanoparticles has provided new opportunities for the fabrication of nano sensors and other devices that are appropriate for human comfort. This chapter provides an overview of the synthesis techniques and various applications. Human comfort can be significantly improved by employing various nanoparticles. The primary innovations now in use and the key sectors of application have been discussed in this brief overview. The synthesis techniques such as sol-gel, chemical vapor deposition, spray pyrolysis, bio-synthesis, spinning disc reactor, mechanical milling, sputtering, thermal decomposition, and laser ablation have been briefly discussed in this chapter. As a result, it is conventional to fabricate sensors that are as small as feasible. As a result of its energy-saving, power-saving, and very small size, subsequent research should concentrate on this attribute for nanoparticle applications. This feature enables the fabrication of several devices that have the capacity to sense multiple gases or atmospheric pollutants.

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