NANOSENSORS: A PROMISING PLATFORM FOR SUSTAINABILITY

Abstract

Nanodetectors which exhibit the potential to measure physical, chemical, biological or environmental information about the nanomaterials and the recognition analytes are known as nanosensors. The information being transformed into data, is efficiently analyzed and interpreted by highly sensitive, specific, accurate and stable nanodetectors, the success of which is attributed to their high surface area to volume ratios. Nanosensor fabrication is an energy efficient, eco-friendly process and a promising tool for the sustainability of agro eco regimes.. Based upon criteria of detection, nanosensors can be electrochemical, electromagnetic, thermal, calorimetric, plasmonic, aptasensors, piezoelectric, optical, hydrogen nanosensors, carbon based nanosensors, non-metallic nanosensors, MOFs (Metal Organic Framework), FRET (Fluorescence Resonance Energy Transfer), Graphene, CNT (Carbon nanotubes), Nanodiamonds etc. Nanosensors find vast applications in diverse fields such as health care, security, monitoring of environment, plant health, pollution, traffic and even human breath. The promising tool still needs investigations and the nanosensor based applications further need to be explored.

Keywords: Nanosensor (NS), Quantum Dots (QD), Nanotubes (NTs), Nanowires (NW), Nanosheets (NS), Graphene, Nanodiamond.

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I. INTRODUCTION

Nanosensors are the tiny sensors made up of sensitive material which exhibits the potential to measure physical, chemical, biological or environmental information about the nanomaterials and recognition molecules at the nanoscale level (Nano is a unit of measurement around 10^{-9} m). The information so acquired is then translated into data for analysis and interpretations. The nanodevices made carry these nanomaterials in the form of nanosensors. Nanosensors exploited under this technique can be larger devices which have detectors or sensors capable of sensing and analyzing at the nanoscale. Conventional modeled sensors had reduced sensing part also known as transducer which is replaced by modern improvised nanosensors. Nanotechnology aims at fabrication of nanoscale products with moderate expense of energy and without the use and production of toxic ingredients. Nanosensors, therefore, are gaining much attention because of increasing demand for detecting and measuring the properties of analytes at the molecular level [5].

II. TYPES OF NANOSENSORS

Based upon the number of analytes to be sensed, nanosensors can be of two types. Nanosensors having special ability to detect only one type of analytes are known as singlex nanosensors[10] and those which are capable of detecting many analytes are known as multiplex nanosensors[31]. Based upon the energy sources, nanosensors can be active or passive NS (Nanosensors). Active NS are those which utilize energy. For example, thermistors. While for passive NS, no energy is required. Examples, piezoelectric thermocouple nanosensors. (Fig.1) Based upon their structure, nanosensors can be of three types:electromagnetic nanosensors, mechanical nanosensors and optical nanosensors. Based on fluorescence measurements, these are made with semi quantum dots. Optical sensors carry probes which contain dyes, the fluorescence of which can be quenched in presence of the analyte to be determined.Use based classification finds nanosensors to be of four types:deployable NS, biosensors, electrometers and chemical nanosensors[1].

Non-metallic nanosensors include organic nanomaterials with some non-metals included in these at the nanoscale. These nanosensing non-metals are useful in biosensing for food inspection. For detection of Ochratoxin in red wine or in grape juice, black phosphorene nanosheet covered glassy carbon electrode is developed recently [33]. β- antagonist found in food can be detected by hexagonal boron nitride nanosheets mounted on multi walled carbon nanotubes up to a limit of 10^{-3} M [34].Besides these, polymer or carbon-based nanomaterials are effective non- metallic nanosensors used in food industry. Depending upon their optical selectivity, many types of nanosensors are possible [21].

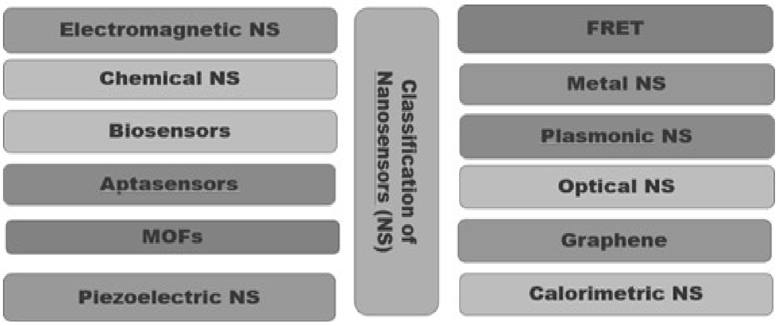

Figure 1: Different types of Nanosensors (NS).

These can be carbon nanotube based NS, QD-based NS, photoacoustic based NS. Nanosensors based upon nanoparticle and nanoclusters are further offour types:

1. **Optical NS:** These are based on measurements of fluorescence or changes in light intensity or reflective index. Semiconductor quantum dots is an example[23] [24].

2. **Carbon Based Electrochemical NS:** Nanosensor based nanowires, nanofibres and carbon nano tubes (CNTs). Carbon nanosensors based on nanotubes (CNTs) are field effect transistors (FET), carbon dots, graphene NS, Nanodiamonds etc. Ultra-selectivity, ultra-sensitivity and capability to detect chemical and biological species make these of use in disease diagnosis, drug discovery and genetic screening [20].

3. **Flexible Hydrogen NS**: Highly sensitive and selective hydrogen gas sensing at room temperature is made possible by employing Pallidium/ Zinc Oxide nanowires. These nanowires are then integrated in nanodevices as effective nanosensors.

4. **Nanosensor Based on Metal Organic Frameworks (MOFs):** Their wide application as nanosensor is based upon their capability to absorb only a specific kind of gas from a group of gases and also to capture iodine as a potentially hazardous molecule from solution [22].

Similarly, **electrochemical NS** measure changes in electrical distribution and corresponding charges and detect the signals at the electrode or a solution interface. They involve redox reactions in which electrons are either released or consumed to result into ions. These electron changes are detected by voltammetric nanosensors[32]. So, the interaction between a ligand and an analyte leads to alteration in transducing signals which are then detected[11].

Piezoelectric NS translate a change in the mass due to chemical adsorption. These measure conversion of mass and viscoelasticity by recording frequency and adjusting quartz crystal resonator. [2]. Change in frequency is detected which is directly proportional to change in mass.

Aptasensors use aptamers for detection of proteins based upon optical mass transduction or electrochemical techniques [4]. Likewise, **thermal NS** make use of biological reactions like assimilation of warmth, regulation of temperature, adjustment of temperature in the reaction medium. Heat so produced is estimated by sensitive thermistors. **Calorimetric NS** measure changes in heat. **Magnetic NS** consists of nanobeads covered with a ligand. These are based upon detection of the magnetic fields.

- **Graphene Nanoparticles:** Graphene based biosensors exploit property of electrical conductivity of graphene to be used in electrical appliances.
- **Fluorescence Resonance Energy Transfer (FRET) Based Nanosensors:** These are meant for detection of DNA, metal ions and organic compounds in addition to detection of biomolecules [35].
- **Plasmonic NS:** Gold, Silver and Platinum NPs are used in these. These are used to monitor events of molecular binding [6].

II. MECHANISM OF ACTION AND SYNTHESIS OF NANOSENSORS

A nanosensor is comprised of an analyte, a sensor, a transducer to convert one form of energy to other and a detector or sensor [13] nanosensors work by tracking the electrical changes brought about in the sensor materials. The analyte diffuses from the solution to the surface of the sensor. After reaction there, it brings about changes in physico chemical properties of the transducer surface that further leads to change in electronic properties of the surface of transducer. This change is converted into electrical signal which is then detected [13](Figure 2.) Nanosensors can be prepared by several methods but mainly three processes are employed for synthesis of nanosensors. Top down lithography, bottom up synthesis and self-assembled nanostructures which are mostly done with biomolecules (Fig. 3.) Concept of Atomic Force Spectroscopy (AFS) regarding the development of nanosensors and nanobiosensors is well documented [5].

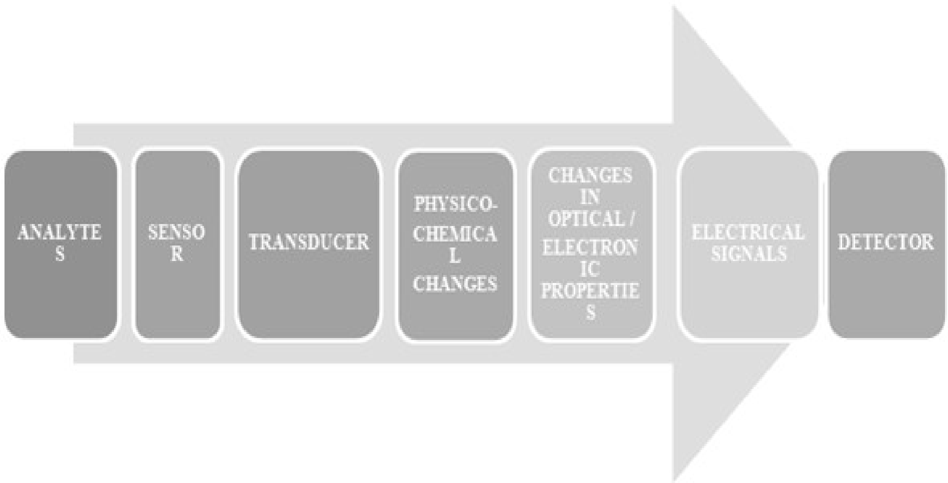

Figure 2: Components and Working Principal of Nanosensors.

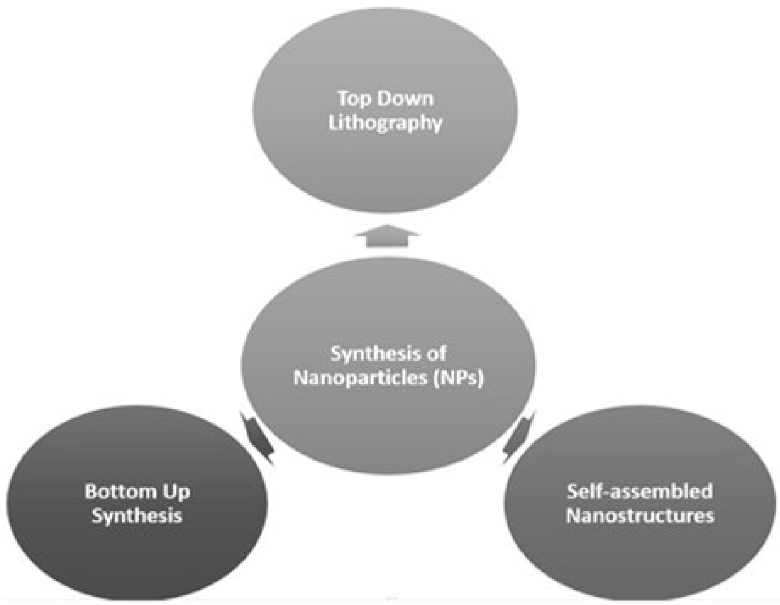

Figure 3: Methods of synthesis of Nanoparticles.

III. PROPERTIES OF NANOSENSORS

Nanomaterials have unique properties which make them entirely different from their bulk properties. They have high surface area to volume ratio due to which they are highly recommended for sensing applications. Nanosensors are highly stable and show specificity towards the analytes. These are dynamic entities and have been reported to be highly selective possessing great diversity, stability, sensitivity, accuracy and speed over the conventional sensors [17]. They show practicable activity, rapid response and excellent execution. These are versatile and very small sized material capable enough for continuous investigations of the analytes[16].

IV. WORKING PRINCIPAL OF DIFFERENT TYPES OF NANOSENSORS

Chemical nanosensors operate by processes like colorimetry, gravimetry or optically. They transform data from the various concentrations of the analyte into a detectable range of signals. This is based upon the analytical capability and chemical selectivity of nanosensors. Nanofibres and nanowires use nanosensors which work by binding antibodies to conductive nanomaterials like carbon nanotubes (CNTs). This binding of antibody brings about changes in the material conductivity [8]. Immunosensors made up of CeO_2 nanoparticles and chitosan can detect food contaminant Ochratoxin A. Similarly, Stappholoccal enterotoxin B is detected by silicon nanowires transistors and Cholera toxin by using CNT. Nanomaterials can also detect microorganisms. For example, TiO_2 coated nanowires with antibodies can detect Listeria monocytogenes [28].

V. APPLICATIONS OF NANOSENSORS

Nanosensors play fundamental and integral role in the development and progress of research in nanotechnology and have wide applications in chemical, food, water quality sensing, medical diagnostics, biomedical, optical and electronic industries (Fig. 4).

1. **Healthcare:** MOFs have gained focus of extensive research as promising candidates for disease diagnosis and drug delivery for a wide range of diseases such as diabetes, cancer, ocular diseases and neurological disorders [26].Graphene nanosensors enable real time monitoring of insulin plasmonicnanosensor gels. Nanosensors are used in medical diagnostics and understanding neurophysiology. Nanowires and nanofibers have been used to build chemiresistive sensors which are of great utility in disease diagnosis. Porous Tin oxide (SnO_2) nanofibers can detect acetone at 0.1ppm and act as biomarker for evaluating diabetes [27]. Graphene foams are used as biomarker for parkinson's disease and real time monitoring of insulin can be done at very low concentration of 35 pM. Also, tattoos of graphene nanosensors can be made to know the monitoring of harmful oral bacteria[25].

2. **Security:** Nanosensors are being used in military for monitoring of terrorism related activities and in aerospace for chemical analysis of atmospheric and soil constituents [17]**.**Graphene foams having high conductivity are very promising as gas sensors and find application in explosive detectors[36].

3. **Environmental Monitoring:** Nanosensors can detect chemical and mechanical information like presence of a chemical and nanoparticles [18]. Nanosensors can be used for detection of physical variables like temperature, humidity, moisture and also electromagnetic radiations in the environment [29]. The quantities detected at nanoscale level are then converted into a corresponding voltage. Nanotemperature sensor is used for measurement of temperature within a range of -200 to +100^{o}C with ±0.5^{o}C accuracy level for which corresponding 3-5 V of DC voltage and 2.5 mA current is required [12]. Similarly, for humidity sensor, soil moisture sensor and rain detectors, there are fixed values for these parameters [3].

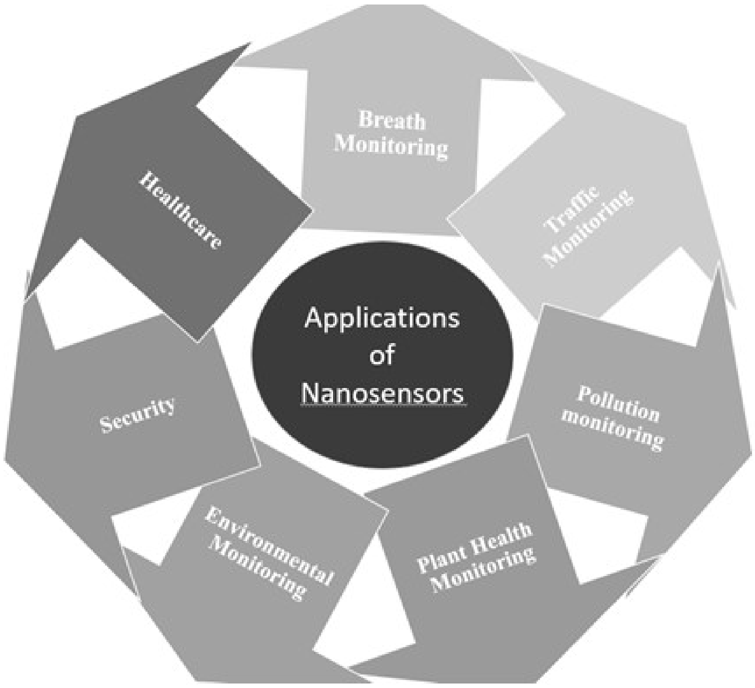

Figure 4: Applications of Nanosensors in different fields.

4. **Plant Health Monitoring:** Nanosensors can provide real time monitoring of plant health. With nanosensors, nutrient requirements, pesticide residue, soil humidity, crop pest identification can be done. Subsequently, excessive use of xenobiotics, pesticides and chemical fertilizers through nanodetectors can be checked which is an energy- efficient and eco- friendly approach. Nanosensors also play a significant role in explaining the role of different molecules in plant system to have better understanding of plant stress due to pests, disease, drought, temperature or pressure.[7].This depends upon the specificity of the detector elements which have been used in the design of nanosensors like aptamers, antibodies, enzymes and some functional proteins. Aptamers and antibodies are the most commonly used detector elements used in nanosensors[14][9].

5. **Pollution Monitoring:** Chemical NS can be employed for monitoring of the pollution by detecting gases, chemicals and biological variables present in water, air and soil. Besides that, nanosensors can also detect explosions and toxins in water [7].

6. **Traffic Monitoring:** Nanosensors are employed for traffic monitoring and for reducing congestion and are known to form a part of intelligent transportation system. The fiber-

optic distributed acoustic sensing (DAS) novel system can automatically detect vehicles and tracking algorithms identifies the trajectory of the vehicles depending upon moving window paradigm. From the output of the tracking stage, a vehicle signature can be extracted which is unique for each vehicle [18]

7. **Breath Monitoring:** ultrafast graphene sensors containing graphene oxide (GO) result into a very sensitive and high speed device that can monitor the breath of the person while speaking. Biomarker imprinted nanosensor can be used as a noninvasive method for detecting VOC (Volatile Organic Compounds) to health issues early using exhaled breath analysis. This is possible due to combination with permeability of water [30].

VI. CONCLUSIONS

Optical biosensors are of great utility for detection of many hazardous metal ions and have shown a promising platform to adopt remediation techniques to tackle the issue of heavy metal ion contaminated waters. Quantum dots is very effective, intelligent and novel luminescent nanosensor that displayed unique and vast potential in today’s sensing industry including biological, biochemical, biomedical and bioimaging fields. Due to their exceptional fluorescence properties, these are used as fluorescent labels [18]. Environmentally sustainable, more energy efficient and inexpensive nanosensors are potential candidates for analyzing and interpreting data effectively and efficiently in diversified fields and hence application based upon them need further investigations.

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