

An overview of Analytical techniques used for the characterisation of bimetallic nanoparticles

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Abstract

Bimetallic nanoparticles are unique class of nanoparticles composed of two different elements. These nanoparticles exhibit enhanced properties compared to their monometallic counterparts due to synergistic effects between the two metals. The superior catalytic, optical and electronic properties of bimetallic nanoparticles make them highly valuable in fields such as catalysis, biomedical and environmental remediation. Characterisation of nanoparticles is crucial to understanding them and optimising their performance. Several techniques can be employed to modify and analyse their morphology, composition etc. Several of the techniques are often used in combination with the other to provide comprehensive insights into their properties.

Keywords: Bimetallic, nanoparticles, techniques, applications, characterisation.

1.0 Introduction

Metallic nanoparticles (MNPs) have emerged as a cornerstone of modern nanotechnology, offering remarkable properties and applications across various scientific and industrial fields [1]. These nanoparticles, typically ranging in size from 1 to 100 nanometers, exhibit unique physical, chemical, and biological characteristics that differ significantly from their bulk counterparts. Using metal nanoparticles can be synthesized by physical, chemical and Biological methods. depending on the number of metals they are called as monometallic, bimetallic and trimetallic nanoparticles. The present article provides an insights into the bimetallic nanoparticles. Bimetallic nanoparticles offer a plethora of advantages that extend their applicability across numerous fields, including catalysis, medicine, environmental science, energy, and electronics. The enhanced catalytic activity, improved stability, unique optical and magnetic properties, and versatility in fictionalization make BNPs an invaluable asset in advancing technology and addressing global challenges[2]. Due to the combination of two different metals these bimetallic nanoparticles acquire distinctive physical ,chemical, mechanical, catalytic , magnetic properties. The particles gain enhanced surface area and mobility. These improved properties make the nanoparticles make them a better alternative over the monometallic nanoparticles and offer more advanced applications[3].

1.1 Classification of nanoparticles:

on the basis of dimension the particles are grouped as zero, one and two dimensional materials. In zero dimensional all the nano sized objects are with in the limits of nanoscale. quantum dots, fullerene are some of the most cite examples in this class. While in one dimensional among all the dimensions, one is not in the scale and in two dimensional two of them are not in the nanoscale range. Nano tubes, rods, wires are few under one dimensional and nanosheets and films , layers are quite few to be seen under two dimensional. Three dimensional nanomaterials are also called as bluk materials because the objects under this will not have any dimension with in the nanorange scale. example are powders[4].

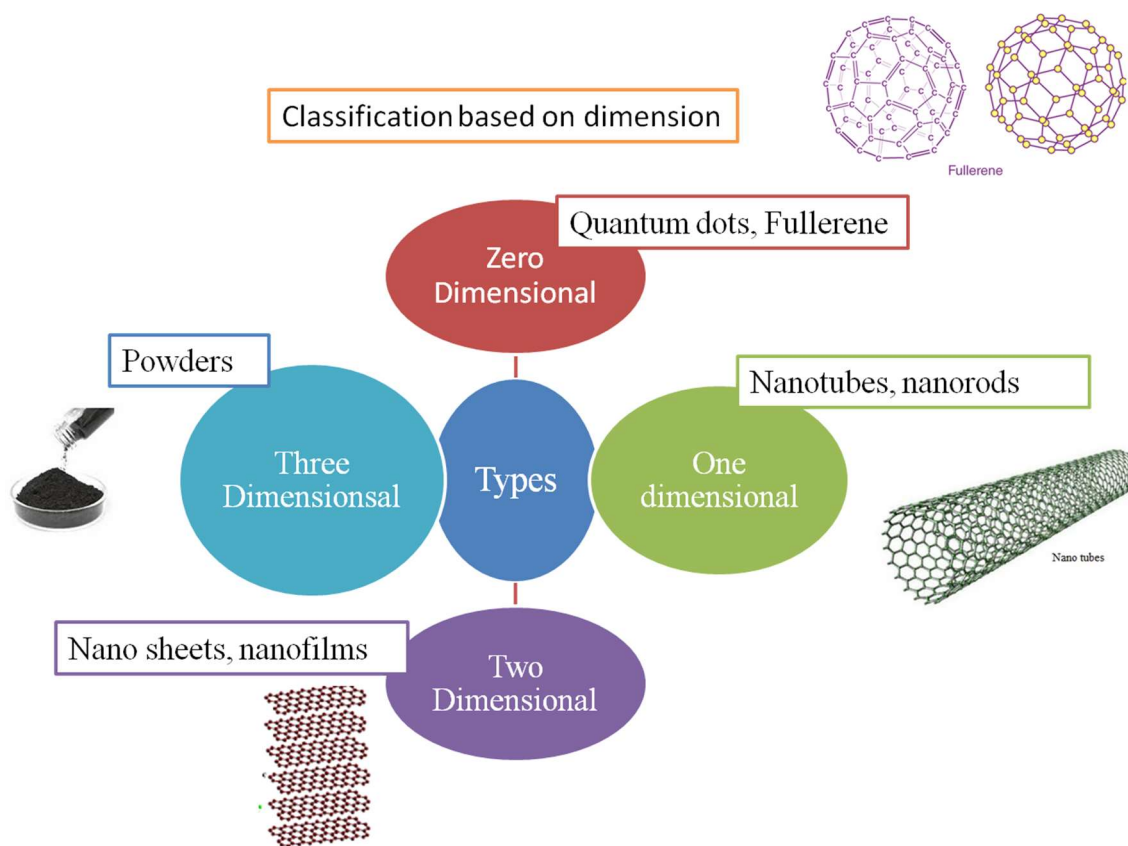


Fig : Classification based on the dimension of nanoparticles

1.2 Synthesis of Bimetallic nanoparticles :

The Methods for the synthesis of nanoparticles can be classified into three different methods under two different approaches. a) Top down approach : in this method the source for the nanoparticles is macromolecule or a bulk material which is then crushed down by various means to give particles that are nano sized. b) Bottom up approach : the initial material used for the synthesis of nanoparticles is tailored to give a nanoparticles. Hence fine particles are constructed into particles of the desired sizes. Among the two types, the morphology of the particles can be regulated by bottom up approach as compared to the former method [5]. The methods of synthesis can be divided into physical, chemical and biological methods.

a) Physical methods: some of the methods under this include laser ablation, mechanical grinding, Ball milling, microwave irradiation, Sputtering, electrochemical method etc[6].

b) Chemical method : sol-gel method, co reduction, precipitation, reduction, micro emulsion method, polymer mediated approach, galvanic mediated approach [6].

c) Biological method : The synthesis of nanoparticles are mediated by using microbes, plants extracts Bio waste [6]

2.0 Characterisation Techniques :

The morphology of the synthesised nanomaterial is very crucial in modulation the characteristic behaviour of particles. Hence from the atom level it is very important to understand and analyse the molecules. Analytical techniques play a significant role in studying and analysing these properties of the molecules and to optimise their application. These techniques can be divided as

1) X-Ray based techniques 2) Spectroscopic based techniques 3) Microscopic based techniques d) Other techniques

2.1) X-Ray based techniques:

A) XRD: X-ray diffraction(XRD) is a non destructive technique. It gives information about the crystallinity, phase of the molecule , nature of the phase, morphology such as shape and size, orientation , chemical composition.. The samples can also be in the powder form while analysing using this techniques. However the techniques, are less reliable for amorphous substance[7]. The technique is often used to identify the nanomaterials, taller the peak the material is considered as crystalline, lower the peaks they are regarded as amorphous[8].

B) XPS : XPS is abbreviated as X-Ray photoelectron spectroscopy. using the analytical technique electronic structure, the composition of the chemical compounds, their oxidation states, ligand binding abilities are studied. It analyses the particles even less than 10nm limitation of this technique is that it can detect all the elements except hydrogen and helium[9].

c) EXAFS(Extended X-Ray absorption fine structure), (SAXS) small-angle X -ray scattering : The instrument allows the observation of bond length changes, and the molecular stress in the presence and absence of temperature. In case of nanoparticles with small size the techniques offers decreased precession such as lower coordination state, or relaxation or contraction of structure of lattice, and more static disorder[10] In deducing the size, shape and distribution of size in a large cluster of nanoparticles, SAXS is one of the most reliable technique[11].

d) EDAX (Energy dispersive X-ray Analysis) : It is most affordable qualitative and quantitative technique to determine the elemental composition of the chemical compounds. The technique is often associated with SEM(Scanning electron microscopy) or TEM (Transmission electron microscope) .The technique also gives information about the concentration of the elements, spatial distribution. Advantage of this technique is that sample can be solid, liquid and powder forms [12].

2.2 Spectroscopy Techniques

a) Raman spectroscopy : It is a type of scattering spectroscopy. The analysis is on the basis of measuring the scattering spectrum with different frequencies from initial incident light to get information on the vibrations of the molecule and rotations. The measurement is based on the chemical bonds with in the sample. Using this

technique the compounds, morphology, crystallinity, phase nature, interactions of molecule, configuration, electronic behaviour of the sample can be analysed. This is a noninvasive method[13].

b) UV spectroscopy : Ultra violet -Visible spectroscopy is simple and sensitive analytical technique used for studying the nanoparticles. The principle of the technique is Beer-Lambert's Law. It is a both qualitative and quantitative technique. UV-Vis spectroscopy is used to study the optical properties of nanoparticles, including their absorption and scattering behavior. The surface plasmon property is very susceptible to refractive index, size, shape, concentrations, agglomeration[14].

c) Mass Spectroscopy : It is a powerful technique used for studying the nanoparticles protein binding studies. It provides information on the protein mixtures, corona identification. It can be associated with liquid chromatography or gas chromatography in most cases depending on the type of sample[15].

D) Spectrofluorimetry: Also called as fluorescence spectroscopy The analysis is based on the fluorescence phenomenon. When the electrons are excited they shift from the ground state to higher energy levels, on returning to the ground state emits the fluorescence light that is measured. The substance the respond to this phenomenon are called as fluorophores. The spectroscopic technique is sensitive to molecular and conformational changes[16].

e) FTIR(Fourier Transform infrared spectroscopy):It is a type of vibrational spectroscopy. Information on the functional group of the molecules is given by FTIR. It confirms the presence of other biomolecules that are attached to the nanoparticles. The characteristic banding pattern helps us to evaluate the groups present and therefore the possible structure of the molecule[17].

f) CD : Circular dichroism is another technique used to study the nanoparticles- biomolecules (protein, DNA) binding studies. The technique resolves the secondary structure of the biomolecules and the change associated due to the attachment of the biomolecules. The technique offers unprecedented sensitivity.

2.3 Microscopic Techniques

a) SEM (Scanning electron microscope) :This microscopic technique provides information on the morphology of the nanoparticles synthesised, its composition, structure, material with which it is made of, distribution. This is often used as a primary characterisation technique and is regularly combined with EDAX[19].(FESEM) field emission scanning electron microscope is a type of SEM which provides images with high resolution[20]

b) TEM (transmission electron microscope): details about the morphology, composition, nature, structure, crystal plane of the material can be obtained with this microscope. High quality images can be capturing images close at a scale close to single atom. It has high resolution when compared to SEM. [19].TEM is a valuable tool in observing the core shell and hollow nanoparticles structure. (HRTEM) High resolution Transmission electron microscope is a variant of TEM with offers resolution to around $0.5\text{\AA}$. In majority of the cases (SAED)selected area electron diffraction is combined with TEM as a result of which selected area diffraction patterns are possible.[20]

C) Atomic Force microscopy AFM: analyse and measure surface regions of the sample using the images captured by the microscopic technique. surface statistics such as roughness, peak to valley region , etc can be measured by this technique. variations in morphology can be deduced and compared to that of reference samples[20]

d) STM(Scanning tunneling microscope): structure of molecules, surface changes, size of particles can be

measured using this microscope. It is both SEM and TEM in operation, hence the microscope provides best superior image quality. (HAADF-STM) High angle annular dark field detector employed in STM assist in collecting maximum possible details of the specimen[20]

2.4 Other Techniques:

a) DLS (Dynamic light scattering) : size distribution of the particles in suspension can be analysed by DLS. sizes in the range of 0.3 to 10,000nm can be measured. It is a quick non invasive technique with minimal sample preparation. There is no limitation on the sample concentration. along with the hydrodynamic diameter, molecular weight also can be deduced [21].

b) Zeta Potential analysis : It calculates the surface charge of the nanoparticles. The stability of the particles and their charges can be acquired by this potential analysis. better quality of the analysis is possible with dilute solutions. Particles with in the range of -10 to +10mV are regarded as neutral particles while those with -30 to +30mV range are strong cation to anion[22].

Conclusion

The future of BNPs lies in continued innovation and interdisciplinary collaboration. Addressing current challenges related to toxicity, environmental impact, scalability, cost, and regulation will be crucial for the successful integration of BNPs into practical applications. Advances in synthesis techniques, characterization methods, computational modeling, and sustainable practices will further enhance the capabilities and applications of BNPs. By embracing the unique properties of bimetallic nanoparticles and investing in research and development, we can unlock their full potential to create sustainable solutions, enhance technological capabilities, and improve the quality of life. The journey of BNPs is just beginning, and their transformative impact on various industries promises a brighter and more sustainable future.

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