Ministry of Higher Education
and Scientific Research
University of Babylon
College of Science
physics department

Silver oxide Synthesis methods and its physical and biological applications

A research project submitted to the Council of the College of Science – Department of Physics
As part of the requirements for obtaining a Bachelor's degree in Physics

by

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1445 A.H 2024 A.D

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة بابل – كلية العلوم

قسم الفيزياء

مشروع بحث تخرج

طرق تصنيع أكسيد الفضة وتطبيقاته الفيزيائية والبيولوجية

للطالبة

عذراء ضياء صالح

بكلوريوس علوم فيزياء

العام الدراسي ٢٠٢٣-٢٠٢٤

بأشراف

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١٤٤٥هجري

٢٠٢٤ ميلادي

بسم الله الرحمن الرحيم

(وَأَنْزَلْنَا إِلَيْكَ الْكِتَابَ بِالْحَقِّ مُصَدِّقًا لِمَا بَيْنَ يَدَيْهِ مِنَ الْكِتَابِ وَمُهَيْمِنًا عَلَيْهِ فَاحْكُمْ بَيْنَهُمْ بِمَا أَنْزَلَ اللَّهُ وَلَا تَتَّبِعْ أَهْوَاءَهُمْ عَمَّا جَاءَكَ مِنَ الْحَقِّ لِكُلٍّ جَعَلْنَا مِنْكُمْ شِرْعَةً وَمِنْهَاجًا وَلَوْ شَاءَ اللَّهُ لَجَعَلَكُمْ أُمَّةً وَاحِدَةً وَلَكِنْ لِيَبْلُوَكُمْ فِي مَا آتَاكُمْ فَاسْتَبِقُوا الْخَيْرَاتِ إِلَى اللَّهِ مَرْجِعُكُمْ جَمِيعًا فَيُنَبِّئُكُمْ بِمَا كُنْتُمْ فِيهِ تَخْتَلِفُونَ)

صدق الله العلي العظيم

(سورة المائدة - الآية (٤٨))

اقرار المشرف

أشهد إن إعداد البحث الموسوم بعنوان {{ Silver oxide Synthesis methods and its physical and biological applications }} ، من قبل الطالبة (عذراء ضياء صالح حنون) قد جرى تحت اشرافي في قسم الفيزياء – كلية العلوم – جامعة بابل كجزء من متطلبات نيل شهادة البكالوريوس في علوم الفيزياء .

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العنوان :- جامعة بابل_ كلية العلوم / قسم الفيزياء

إهداء

إلى أمي رمز التضحية والعطاء ...

إلى والدي الذي اعطاني الثقة كي أستمر ...

إلى أشقائي الذين كانوا نعم السند لي ...

إلى كل من آمن بي ودعمني خلال مسيرتي ...

إلى كل من طلب العلم وابتغى إليه سبيلاً ...

أهدي إليكم جميعاً ثمرة هذا الجهد

سائله المولى عز وجل أن ينفعنا به وأن يتقبله ويجعله في ميزان حسناتي

الباحثة

الشكر والعرفان

لا يسعنا بعد الانتهاء من إعداد هذا البحث إلا أن أتقدم بجزيل الشكر وعظيم الامتنان إلى استاذي الفاضل

الدكتور حكمت عدنان جواد

الذي تفضل بالإشراف على هذا البحث ، حيث قدم لي كل النصح والإرشاد طيلة فترة الإعداد فله مني كل الشكر والتقدير .

كما لا يفوتني أن أتقدم بجزيل الشكر والعرفان إلى كل دكاترة

قسم الفيزياء – كلية العلوم – جامعة بابل .

لهم مني كل الشكر و التقدير .

الباحثة

Abstract

Among the emerging nanotechnology, nanoparticles get much attention due to their unique physicochemical, optical, electrical, and thermal activities. Nowadays, extensive research on silver nanoparticles is going on due to their wide applicability in different fields. Silver nanoparticles possess excellent anticancer as well as antimicrobial efficacy (hence found major and wide applications as antimicrobial, wound healing, antidiarrheal, and antifungal agents). A huge and advanced perspective of silver nanoparticles is found in environmental hygiene and sterilization due to their magnificent disinfectant properties. The other major applications of silver nanoparticles include diagnostic (as biological tags in biosensors, assays, and quantitative detection), conductive (in conductive inks, pastes, and fillers), optical (metal-enhanced fluorescence and surface-enhanced Raman scattering), and household (pesticides and wastewater treatment) applications. The present review consists of an exhaustive detail about the biological and physical applications of silver nanoparticles along with the analysis of historical evolution, the present scenario, and possible future outcomes.

الخلاصة

من بين تكنولوجيا النانو الناشئة، تحظى الجسيمات النانوية باهتمام كبير بسبب أنشطتها الفيزيائية والكيميائية والبصرية والكهربائية والحرارية الفريدة. في الوقت الحاضر، تجري أبحاث مكثفة حول جسيمات الفضة النانوية نظرًا لإمكانية تطبيقها على نطاق واسع في مجالات مختلفة. تمتلك الجسيمات النانوية الفضية مقاومة ممتازة للسرطان بالإضافة إلى فعالية مضادة للميكروبات (وبالتالي وجدت تطبيقات كبيرة وواسعة مثل مضادات الميكروبات، وتضميد الجراح، ومضادات الإسهال، والعوامل المضادة للفطريات). يوجد منظور ضخم ومتقدم لجزيئات الفضة النانوية في نظافة البيئة والتعقيم نظرًا لخصائصها المطهرة الرائعة. تشمل التطبيقات الرئيسية الأخرى لجسيمات الفضة النانوية التشخيص (كعلامات بيولوجية في أجهزة الاستشعار الحيوية، والمقايسات، والكشف الكمي)، وموصل (في الأحبار الموصلة، والمعاجين، والمواد المالئة)، والبصرية (الفلورية المعززة بالمعادن وتشتت رامان المعزز على السطح)، والتطبيقات التطبيقات المنزلية (المبيدات الحشرية ومعالجة مياه الصرف الصحي). تتكون المراجعة الحالية من تفاصيل شاملة حول التطبيقات البيولوجية والفيزيائية لجسيمات الفضة النانوية إلى جانب تحليل التطور التاريخي والسيناريو الحالي والنتائج المستقبلية المحتملة.

Contents

NO	Subject	Page
	Abstract	
	Chapter one : Introduction	
1.1	*Introduction*	1
1.2	*Structure of Silver Oxide*	2
1.3	*electrical proper tes*	3
1.4	*optical Propertes*	6
1.4.1	*The Effect of Size on Optical Properties*	6
1.4.2	*The Effect of Local Refractive Index on Optical Properties*	7
1.4.3	*The Effect of Aggregation on Optical Properties*	8
1.5	*Morphological properties*	9
1.6	*Uses of Silver Oxide*	11
1.7	*The aim of the research*	13
	Chapter Two : Synthesis of Silver Oxide (AgO)	
2.1	*Methods of silver oxide (AgO) synthesis*	15
2.2	*Physical Methods*	16
2.3	*Chemicals Methods*	17
2.4	*Characterization of AgO*	19
	Chapter Three : applications physical and biological	
3.1	*Introduction*	25
3.2	*biological applications*	25
3.3	*physical applications*	31
	Conclusion	40
	References	41-50

Chapter one

Introduction

Chapter one

1.1 Introduction

Silver oxide can be defined as the chemical compound with the formula Ag_2O, which is a fine black or dark brown colored powder and is used to prepare other silver compounds. This odorless powder is used primarily for polishing glass, for the purification of water, and coloring glass. Silver oxide can be prepared by combining aqueous solutions of silver nitrate and sodium or potassium hydroxide. Moreover, silver oxides, both Ag_2O, and AgO serve as the cathodic materials in silver zinc primary and secondary batteries. And the high energy density of the primary batteries is responsible for their working as miniature power cells.[1]

Silver oxide is an inorganic fabricated compound made out of two particles of silver and the slightest bit of oxygen. The sub-atomic recipe of silver oxide is Ag_2O. Its IUPAC name is silver(I) oxide. In silver(I) oxide, (I) shows here the oxidation number of silver which is +1. It is a dull or weak generous shaded covered compound. It is basically utilized in batteries and in the readiness of other silver mixes. It is by and large called silver development, argentous oxide, and silver monoxide. [2]

Fig (1-1) Silver oxides[3]

Silver oxides (both Ag2O and AgO) fill in as the cathodic materials in silver-zinc crucial and partner (i.e., battery-powered) batteries. The high energy of the imperative batteries is submitted for their work as scaled-back power cells for cameras and watches.

1.2 Structure of Silver Oxide

To be precise, AgO is diamagnetic despite the fact that the empirical formula signifying that silver is in the oxidation state of +2 within the compound. There are two different types of coordination environments based on the studies on X-ray diffraction viz. one with two collinear oxide neighbors and the second with neighbors of four coplanar oxides. The formula for AgO would be $Ag_2O·Ag_2O_3$ or AgI AgIIIO_2. [4]

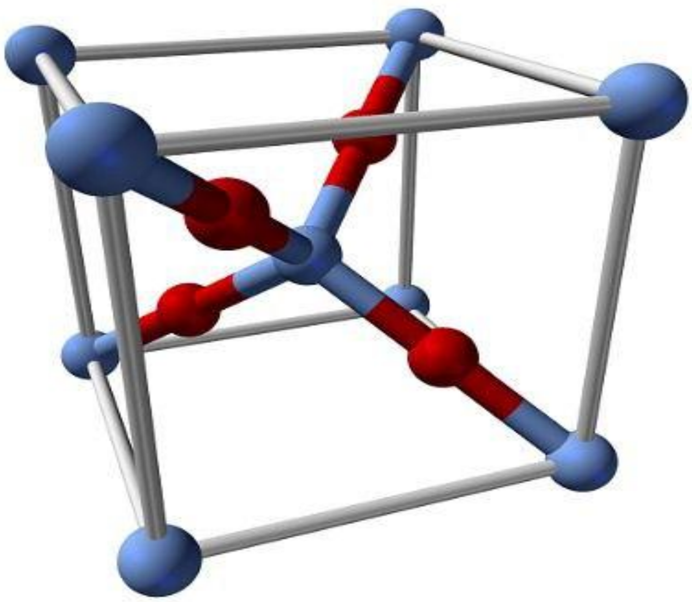

Fig (1-2) Structure of Silver Oxide[4]

1.3 electrical properties

Several studies on silver oxide are focused on the electrode reactions in battery applications . There is very limited literature available on silver oxide thin films . Silver oxide (Ag_2O) is a p - type semiconductor with a band gap of 1.2 eV . The oxygen vacancies seem to play a dominant role in the conduction mechanism of silver oxide films . These films may be prepared by several techniques and there have been limited studies on these films . The recent studies have shown that nano clustures of silver oxide give raise to a fluorescent phenomena (after subjecting the film to 515 nm irradiation) which may be used in optical data storage . Also , silver doping in indium oxide (IO) thin film seems to have very interesting observations in the electrical properties , namely , type conversion (from n to p) with varying oxygen stoichiometry in the film . Thus the silver oxide thin films are giving raise to a new set of materials : p - type transparent conducting oxide (TCO) thin films . [5]

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Thus the silver oxide thin films are giving raise to a new set of materials : p - type transparent conducting oxide (TCO) thin films. [6]

Ag is a suitable metal for use as a back electrode in organic semiconductors due to its high reflectivity, conductivity and uniformity . However, in generally, Ag is not considered as an ideal electrode for charge injection/collection for organic semiconductors due to its work function (~4.3 eV). Typically, for cathodes, the work function should be lower than 3 eV, while for anodes, the work function should be higher than 5 eV for efficient charge injection/collection from the active layer. For organic semiconductor devices, the barrier height (defined as the difference between the work function of the anode and the ionization potential of the organic layer) should be low, in order to boost the performance through balancing charge carriers in the active layer. Molybdenum trioxide (MoO3) is one of the most promising materials for use as a buffer layer to facilitate hole transfer from the organic active layer to the anode in organic semiconductor devices because of its non-toxic nature, easy thermal evaporation and good energy level matching . However, evaporation of ultra-thin (< 20 nm) MoO3 layers on Ag that are continuous and uniform is a challenge. [7] Although increasing the thickness of the MoO3 layer can avoid deficiencies, thicker MoO3 layers will decrease the conductivity of devices, the optical transmission and the number of carriers transferred between the organic material and the electrode. Alternatively, the barrier height between Ag anodes and organic materials can be altered by controlling the surface composition of the Ag, especially by inducing a thin, native oxide on the surface of Ag directly. [8]

Silver oxide (AgOx) has already been used in batteries as an electrode material because of its transparent characteristics. In addition, AgOx films exhibit p-type semiconducting properties with a work function greater than 5 eV . The work function of the AgOx films is much higher than that of pure Ag and makes AgOx a suitable hole transport layer for most organic optoelectronic devices. Addition of surface oxides to silver is expected to improve stability in ambient conditions over time and to eliminate the need for additional hole transport/electron blocking layers in the optoelectronic configuration. In previous work, various techniques had been reported for the preparation of AgOx thin films, such as: sputtering or thermal evaporation of Ag in an oxygen atmosphere; reactive electron beam (E-beam) evaporation of silver oxide; and UV-ozone treatment of Ag films. [9]

In this study, our goal is to assess the feasibility of building an inverted organic semiconductor device on top of a Ag electrode and of adding a native silver oxide layer on Ag electrodes to function as hole transport layers. X-ray photoelectron spectra (XPS) is used to confirm the chemical composition of the Ag surface before and after exposing it to an O2/Ar plasma for different durations . The morphological changes of the surface-oxidized Ag films are observed by using scanning electron microscopy (SEM) and dark-field (DF) optical microscopy. Current density-voltage (J-V) characteristics of poly(9,9-dioctylfluorene-alt-benzothiadiazole) (F8BT) hole-only devices are measured to show the differences in turn-on voltage of devices with different layers between the Ag electrode and the F8BT active layer, and barrier heights are calculated. In addition, changes in the electrical properties of these devices over time are characterized to investigate their stabilities with different hole transport layers. The electrical properties of devices with AgOx hole transport layers are compared to devices with MoO3 as a hole transport layer between the Ag electrode and the polymer active layer. [9]

1.4 optical Properties

Silver particles absorb and scatter light with extraordinary efficiency. Their strong interaction with light occurs because the conduction electrons on the metal surface undergo a collective oscillation when excited by light at specific wavelengths. This oscillation is known as surface plasmon resonance (SPR), and it causes the absorption and scattering intensities of silver oxide particles to be much higher than those of non-plasmonic silver particles of similar size. The absorption and scattering properties of silver particles can be tuned by controlling the particle size, shape, and local refractive index near the particle surface. [10]

1.4.1 The Effect of Size on Optical Properties

The optical properties of spherical silver nanoparticles are highly dependent on the nanoparticle diameter. The extinction spectra of 10 sizes of NanoXact Silver nanoparticles at identical mass concentrations (0.02 mg/mL) are displayed in the figure (1-3) below . Smaller nanospheres primarily absorb light and have peaks near 400 nm, while larger spheres exhibit increased scattering and have peaks that broaden and shift towards longer wavelengths (known as red-shifting). Paramelle et al. [11]

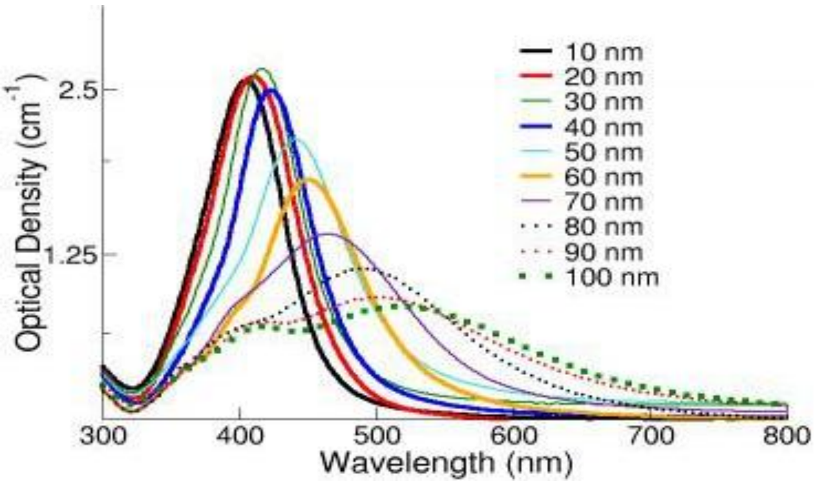


Fig (1-3) The extinction spectra of 10 sizes of NanoXact Silver nanoparticles at identical mass concentrations (0.02 mg/mL) are displayed . [11]

1.4.2 The Effect of Local Refractive Index on Optical Properties

Silver nanoparticle optical properties also depend on the refractive index near the nanoparticle surface. As the refractive index near the nanoparticle surface increases, the nanoparticle extinction spectrum shifts to longer wavelengths (known as red-shifting). Practically, this means that the nanoparticle extinction peak location will shift to shorter wavelengths (blue-shift) if the particles are transferred from water (n=1.33) to air (n=1.00), or shift to longerwavelengths if the particles are transferred to oil (n=1.5). The figure (1-3) below displays the extinction spectrum of a 50 nm silver nanosphere as the local refractive index is increased. Increasing the refractive index from 1.00 to 1.60 results in an extinction peak shift of over 90 nm, moving the peak from the ultraviolet to the visible region of the spectrum. [12]

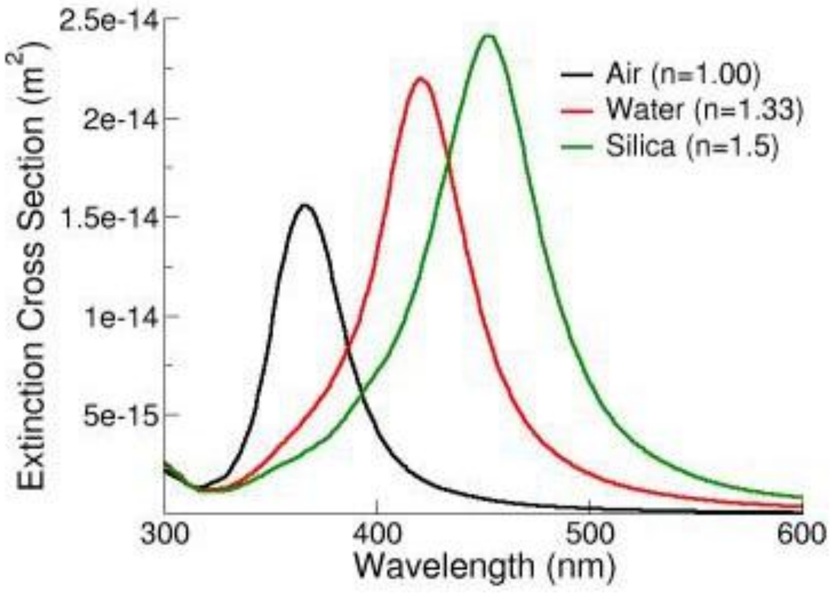
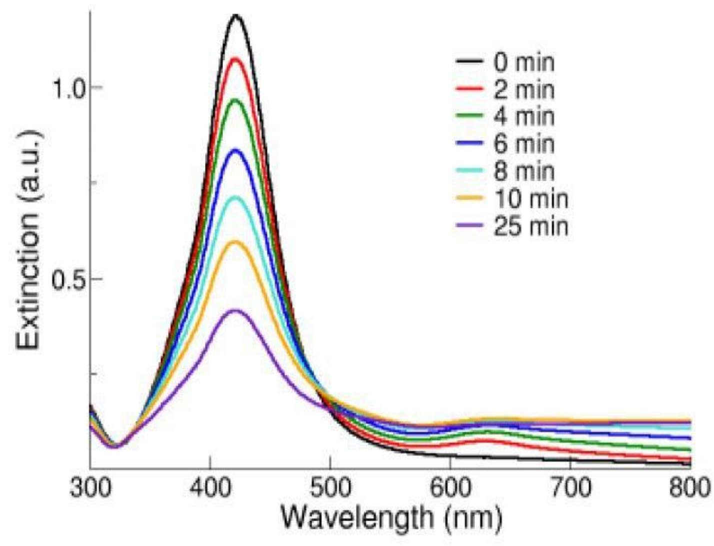


Fig (1-4) The extinction spectrum of a 50 nm silver nanosphere as the local refractive index is increased. [12]

Similarly, the extinction peak can be tuned by coating aqueous nanoparticles with nonconducting shells including silica (n=1.5), biomolecules (n=1.4-1.45), or aluminium oxide (n=1.58-1.68). [13]

1.4.3 The Effect of Aggregation on Optical Properties

The optical properties of silver nanoparticles change when particles aggregate and the conduction electrons near each particle surface become delocalized and are shared amongst neighbouring particles. When this occurs, the surface plasmon resonance shifts to lower energies, causing the absorption and scattering peaks to red-shift to longer wavelengths. UV-Visible spectroscopy can be used as a simple and reliable method for monitoring the stability of nanoparticle solutions. As the particles destabilize, the original extinction peak will decrease in intensity (due to the depletion of stable nanoparticles), and often the peak will broaden or a secondary peak will form at longer wavelengths (due to the formation of aggregates). In the figure below, the extinction spectrum of 50 nm NanoXact silver is monitored as sodium carbonate is added to the solution (20 mM salt concentration). The rapid and irreversible change in the extinction spectrum clearly demonstrates that the nanoparticles are agglomerating. UV/Visible spectroscopy can be used as a characterization technique that provides information on whether the nanoparticle solution has destabilized over time. [14]



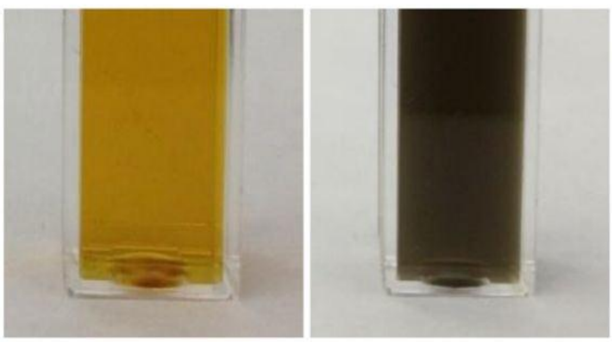


Fig (1-5) the extinction spectrum of 50 nm NanoXact silver is monitored as sodium carbonate is added to the solution (20 mM salt concentration). [15]

1.5 Morphological properties

Fig (4) represents the surface sections of the as - deposited silver oxide thin films . As clearly seen from Fig (4) , all samples shows different phases or morphological structures . This result agreed with the XRD study . The lowest film thickness (54 nm) shows fine crystallites titled and aligned in parallel mode . Furthermore , the presence of large sheets and particles are also observed . The tilting of such crystallites , sheets , or particles may be due to specific planes of Ag_2O , Ag_2O3 and Ago phases . The large sheets have irregular shape for lowest film thickness converted to smooth and regular sheets when the film thickness increases to 116 nm . Also , the fine crystallites number appears more than that observed at lower thickness and randomly distributed through the layers . By increasing the film thickness to 180 nm , the sheets have irregular shapes and aggregates on the surface film . The fine crystallites and the big particles in Ag3 sample are observed to be less than Agl sample . The same behavior is also observed for the largest film thickness (236 nm) but with only some few big particles . [16]

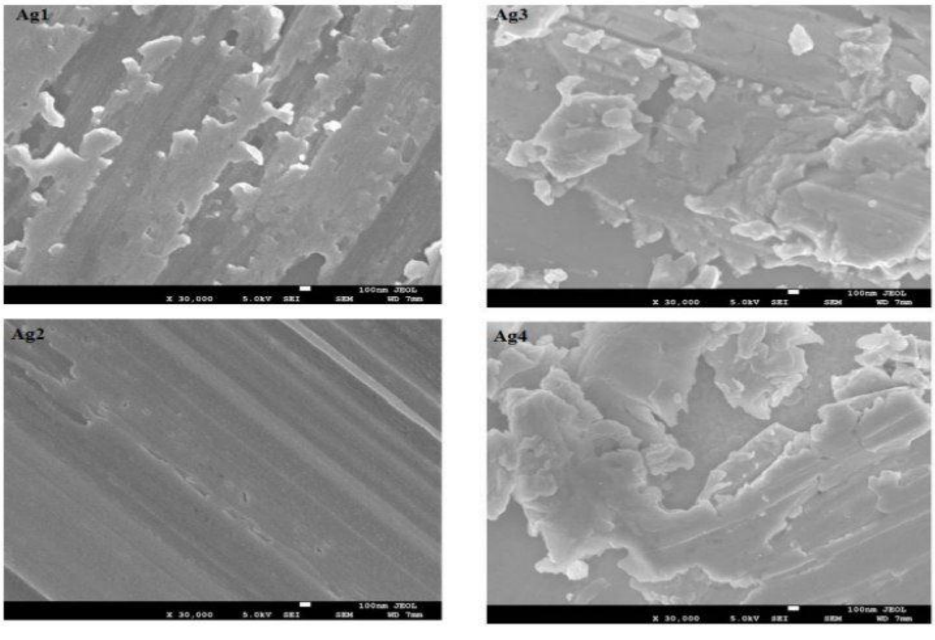


Fig (1-6) : SEM images of the as - deposited films . [17]

For the annealing films at 450 ° C for 4h , the morphological surface is seen to be more clearly and distinguishable as observed in Fig (5) . The phase separation phenomenon is also observed through all samples . Hence , different phases are detected in all surface patterns . For the lowest film thickness (54 nm) , three types of phases are clearly observed . Fine particles and aggregated small particles are randomly distributed through the surface pattern . Also medium irregular sheets are also presented . These sheets become larger in size for films of thickness (116 nm) . The morphological structure of Ag3 and Ag4 samples is quite different especially the Ag3 sample which has pores . The size of sheets becomes smaller than Ag1 and Ag2 samples . Few fine particles can also be detected . The pores are decreased for films of thickness (236 nm) and the sheets become larger in size . [17]

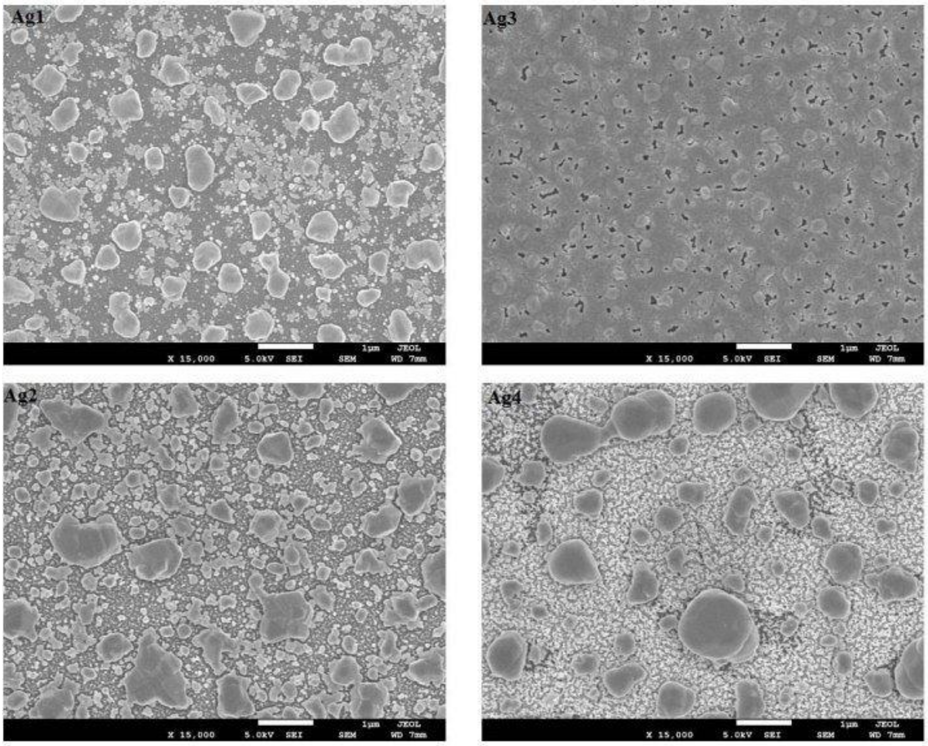


Fig (1-7) : Morphological surface of the annealing films at 250 ° C . [18]

1.6 Uses of Silver Oxide

Silver oxide is a chemical compound . This fine dry powder with a brownish - black color is primarily used in the preparation of other silver compounds . It is a three - dimensional polymer (i.e. chemical compound consisting essentially of repeating structural units) and is not readily soluble in most solvents . Although silver oxide hydrolyzes only slightly in water , it gives the water a distinctive metallic taste . However , silver oxide is soluble in dilute nitric acid and is easily attacked by acids . Like other silver compounds , silver oxide is not light sensitive and decomposes at temperatures above 280 degrees Celsius . It has many uses, including :- [19]

❖ **Laboratory Reagent**

Silver oxide is used as a reagent in laboratory reactions to form various chemical compounds . It dissolves in ammonium hydroxide solutions to give soluble derivatives . Also , silver oxide reacts with alkali chloride solutions to yield alkali hydroxide . It is often employed in the synthesis of transition metal carbene complexes (i.e. organometallic compound featuring a divalent organic ligand) . For example , silver oxide readily reacts with ligand precursors to form the corresponding complexes . [20]

❖ **Carbon Dioxide Scrubber**

Silver oxide is very effective in removing (or scrubbing) carbon dioxide from humidified air (humidity greater than 25 percent) . This property is extensively used in nuclear submarines , the international space station and space shuttles . Silver oxide reacts with carbon dioxide in the presence of water to generate silver carbonate . It is capable of regenerating all the scrubbed carbon dioxide by prolonged heating , which enables each canister (

a perforated metal box that absorbs airborne poisons and irritants) to be recycled about 60 times .

❖ **In the Manufacture of Pollution Control Filter**

Silver oxide is used in the manufacture of filters for gas sensors . This filter helps increase the efficiency of chlorine dioxide detectors to free the gas stream from hydrogen sulfides without producing any unwanted compounds .

❖ **In the Manufacture of Silver Oxide Batteries**

Silver oxide and zinc form the main components of a silver oxide battery (also called silver -zinc battery) . While silver oxide acts as the positive electrode (cathode) , zinc behaves as the negative electrode (anode) . Unlike its competitor counterparts , a silver oxide battery has higher durability , can handle higher current loads , and is free from thermal runaways and inflammability . Such batteries are used in electronic devices as well as U.S. military and Apollo space programs . [21]

❖ **Antimicrobial Agent**

Silver oxide has enhanced antimicrobial properties and is often used in the manufacture of some infection - resistant surgical fabric materials and fibrous textile articles . It is also used in concrete and in some swimming pools and spas to protect the water from undesired microbes . [22]

1.7 The aim of the research

1) Identify silver oxide, as well as its optical, electrical, and morphological properties .
2) Learn about the uses of silver oxide
3) Study how to prepare silver oxide in different ways .
4) Learn about the physical and biological applications of silver oxide.

Chapter Two

Synthesis of Silver Oxide (AgO)

Chapter Two

2.1 Methods of silver oxide (AgO) synthesis

The synthesis methods of Ag_2O There are numerous techniques that can be used to produce silver oxide nanoparticles . Either a " Top down " or a " Bottom up " technique can typically be used for the synthesis of Ag_2O . Using physical processes to size - reduce bulk materials , the top - down ap proach produces nanoparticles . Silver Oxide NPs are produced via chemical and biological processes in the bottom - up strategy , which is shown in figure (2-1) . [23]

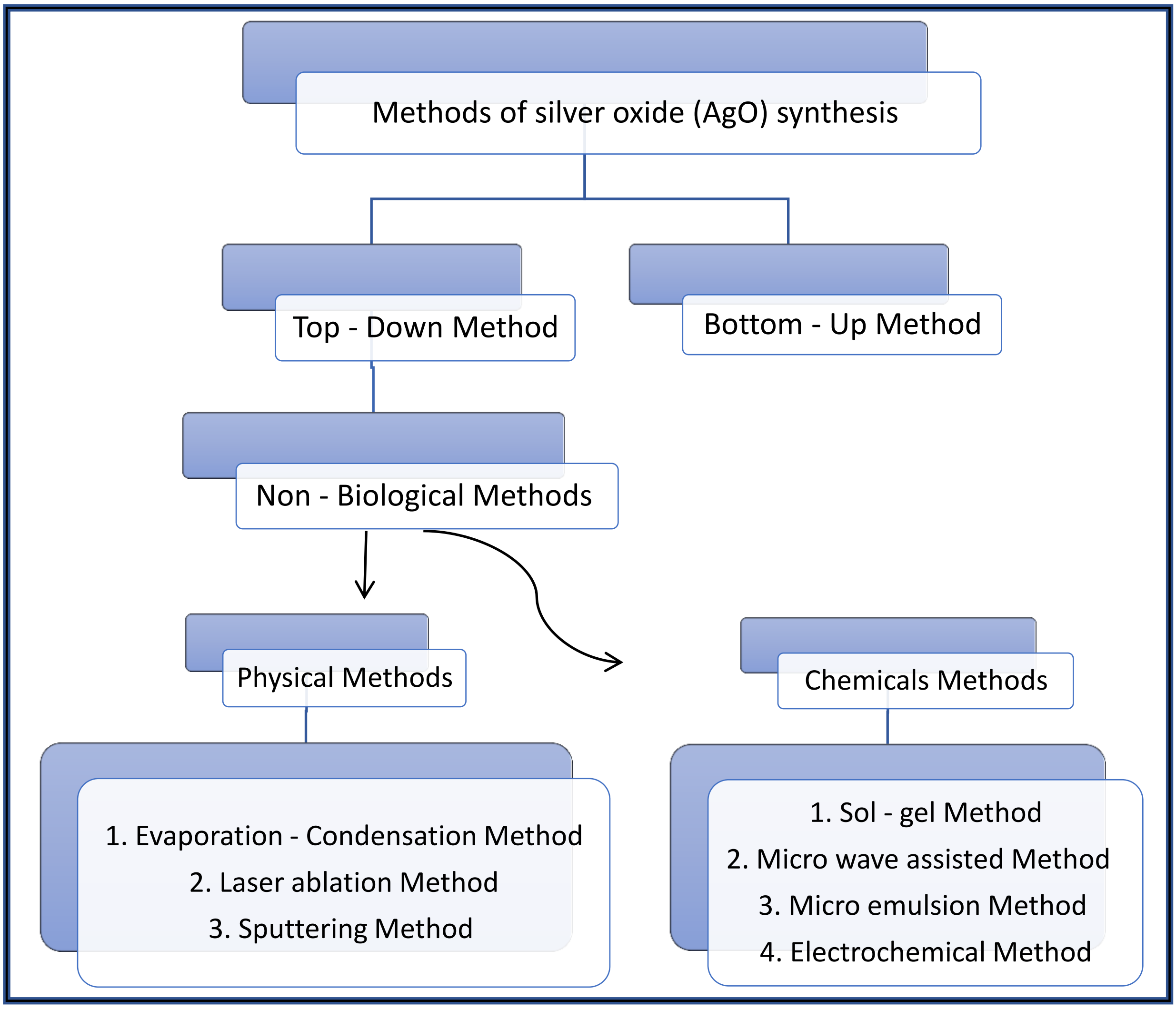


Fig (2-1) : Methods of AgO Synthesis . [24]

2.2 Physical Methods

2.2.1 Evaporation - Condensation Method

Physical processes such as evaporation - condensation , which can be performed in a tube furnace under air pressure , are gener ally utilized for producing Ag_2O . A carrier gas is created by the evaporation of the material source inside a boat - shaped furnace . Recently , the Evaporation - Condensation method has been utilized for producing nanoparticles made of a variety of materials , includ ing Ag and Au . However , there are several drawbacks to producing Ag , ONPs in a tube furnace since it takes up lots of room , consumes lots of energy even after raising the temperature around the source material , requires longer time for thermal stability . To achieve a consistent working temperature , a typical tube boiler must con sume many kilowatts of power and pre - heat for many minutes .

2.2.2 Laser ablation Method

By using laser ablation , the laser's radiation is employed to re duce the particle size to the nanoscale . The solid target material is positioned behind a thin layer and then exposed to pulsed laser light . When materials are exposed to laser light , the solid substance is broken up into tiny NPs , which stay in the liquid that surrounds the target and also produce colloidal solution . The amount of ab lated atoms and Ag , ONPS produced depends on the length of the laser pulse and its energy . [25]

2.2.3 Sputtering Method

Sputtering entails pounding a hard surface with high - energy gas - like particle bombardments in order to produce Ag , ONPs . Ap proaches for sputtering are believed to be effective for producing thin films of nanomaterials . An evacuated chamber is given the sputtering gas to begin the sputtering process . Then a high voltage is delivered to the cathode that is the target , making free electrons to clash with the gas as they go there , producing gas ions . The cath ode target is struck repeatedly by powerfully accelerated positively charged ions in electric fields , causing an atom discharge on the target's surface . The sputtered Ag , ONPs composition is identical to the target material having less impurities , making the sputtering technique attractive . It is also cheaper than electron beam lithog raphy . [26]

2.3 Chemicals Methods

2.3.1 Sol - gel Method

The sol gel approach makes use of a wide range of superior nanomaterials based on Ag_2O . The current procedure is called as a " sol - gel method " for the reason that an aqueous precursor is converted to a sol during the manufacture of Ag_2O , and the sol is then transformed into a network structure called as gel . Particle size can be checked by varying the precursor concentration , tem perature , and pH values . It takes a mature stage to allow the evolu tion of solid mass ; it can take a few days for the solvent to evaporate and phase shifts to take place . Ag_2O are produced by separating the unstable ingredients . [27]

2.3.2 Micro wave assisted Method

Nanotechnology as well as biological pathways are two areas where microwave assisted technique is frequently employed . Com pared to conventional convective heat treatments , chemical reac tions frequently occur faster , with higher yields , and with fewer byproducts . Microwave reactors are effective at controlling the re action mixture , can resist high temperatures as well as pressures , and can produce predictable reaction responses . The utilization of microwave - assisted methodologies enables enhanced engineering regulation of the separation between the nucleation and growth stages during the formation of silver oxide nanoparticles when the reaction is started at ambient temperature . It's possible that micro wave - assisted heating is to blame for part of the sensitivity in stim ulating precursor materials for nanomaterials , which is essential for scalability . In order to prepare silver oxide nanoparticles , The process of microwave - assisted preparation possesses the ability to differentially heat either the solvent or the catalyst molecules . [28]

2.3.3 Micro emulsion Method

The micro emulsion approach promises to be the flexible meth ods of preparation that enables the formation of particle attributes such as geometry , surface characteristics , homogeneity , surface characteristics as well as mechanisms for controlling particle size The micro emulsion approach is widely used in both chemical and biological fields . [29]

2.3.4 Electrochemical Method

Chemical fluctuations are caused by the passage and conduc tions of an electronic flow through an electrolytic solution . Two metal electrodes , the anode as well as the cathode , are submerged in electrolytic solutions that include metal salts and a stabilizing agent while also having an electric voltage applied across them in an electrochemical process . This process involves a constant elec tric current flowing into the electrolytic cells , which ionizes the metal salt solution and causes it to dissociate . The metal sheet is dissolved , the anode goes through oxidation , and the cathode goes through intermediate salt reduction . Dropped metal from the an ode terminal onto the cathode plates . M molecules in the form of NPs are painstakingly collected from the cathode terminal toward the end of electrolysis . [30]

2.4 Characterization of Ag_2O

Characterizing silver oxide nanoparticles , also known as Ag_20 , is essential to gaining a knowledge of the size , shape , struc ture , composition , and physicochemical characteristics of these particles . The following is a list of some of the more prevalent ap proaches for characterizing these nanoparticles shown in figure (2-2) . [31]

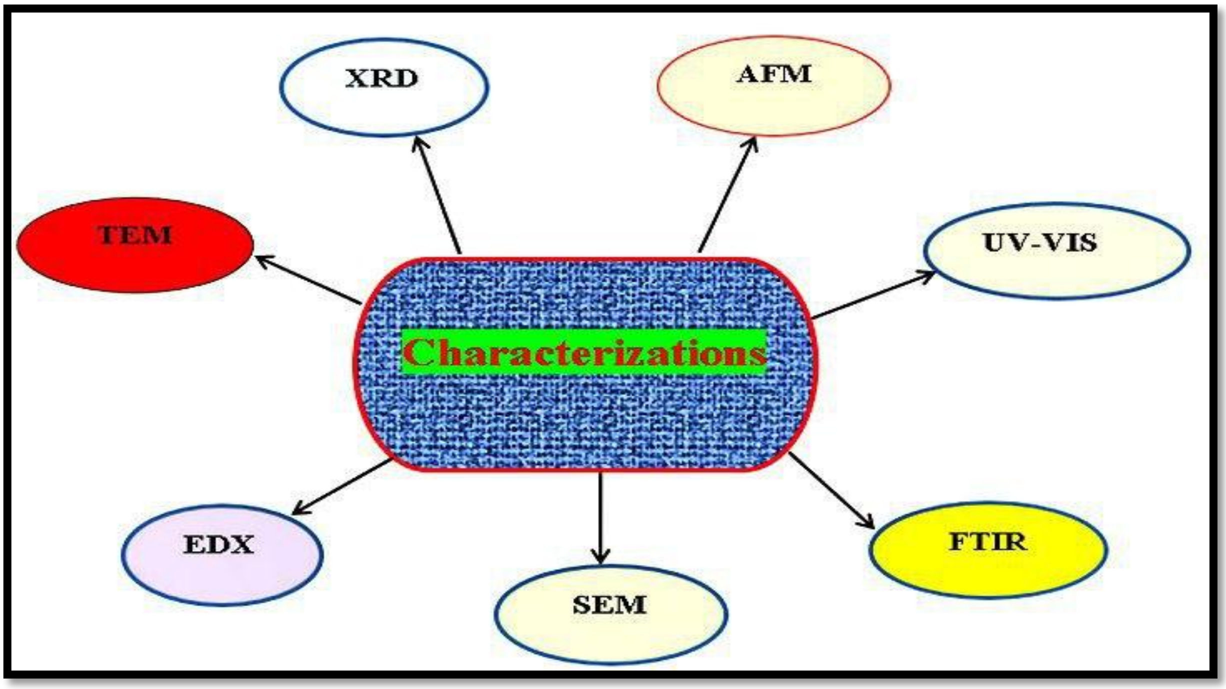


Fig (2-2) : Various Characterization Techniques. [31]

2.4.1 UV - visible spectroscopy

The optical absorbance as well as bandgap of the Ag_2O are determined using UV - Vis absorption spectroscopy . Based on their absorption , this method is used to identify and explain metal - based nanomaterials . While the size range for characteriza tion of Ag_2O by UV - Vis absorption spectroscopy is 2-100 nm , the nanoparticle size level varies from different metals . Ag_2O have a wave length range between 200 and 800 nm , and a UV - Vis spectrophotometer can detect them . Under specific salt - synthesis conditions , metallic nanoparticles exhibit significant absorption to produce a point spectrum in the detectable region . Earlier research findings shown that the absorption of wavelengths 200-800 was suitable for classifying nanoparticles with sizes between 2-100 nm . [32]

2.4.2 Scanning electron microscopy (SEM)

SEM is capable of characterizing Ag_2O . This instrumentation study aims to characterize the distribution , size , morphology , and form of silver oxide nanoparticles . The SEM study measured how a morphological structure changed both before and after treatment . According to earlier research , observable changes in cell shape as well as nanoparticle perforations in the cell wall have been em ployed a sign for antibacterial effect of Ag , O produced through phytosynthesis had their surface shape determined using SEM [33].

2.4.3 Transmission electron microscopy (TEM)

The crystal structure as well as particle size of the material were classified and verified using transmission electron micros copy (TEM) at the nanoscale level . The morphology as well as di mensions of Ag_2O were determined using transmission elec tronic microscopy (TEM) . The sample was created by pouring the Ag_2O solution onto a copper grid that had been coated with carbon and then setting it on a specimen holder . TEM images were used to verify the Ag_2O ' sizes and forms . [34]

2.4.4 X - ray diffraction (XRD)

XRD is able to study the atomic structures of materials . The quantitative as well as qualitative levels of materials can be de termined with the use of this technology . Crystalline nanoparticle shapes and sizes were identified and verified using XRD analysis . Applying the Debye - Scherrer formula to determine the width of the Bragg reflection law according to the equation : d =

KX / B cos 0 , where d is the particle size (nm) , K is the Scherrer constant , λ is the X - ray wavelength , ß is the full width half maximum , and 0 is the diffraction angle (half of Bragg angle) that corresponds to the lattice plane , allowed for the analysis of the particle dimension of nanomaterials from XRD data . Every crystalline substance has a unique diffraction pattern that can be utilized to detect the crystal line structure and nanoparticle morphology using X - ray diffraction (XRD) . [35]

2.4.5 Fourier transform infrared spectroscopy (FTIR)

In order to reduce , stabilize , and cap Ag_2O , a functional group must be found using Fourier transform - infrared (FTIR) spectroscopy . In FTIR analysis , the sample is exposed to infrared red rays , some of which are absorbed by it , and the remainder of which pass through . The spectrum shows wavelength - dependent absorption or transmission , which describes the sample materi als . A good , affordable , straightforward , and non - invasive method to identify the role of biomolecules in the reduction of Ag , O is FTIR analysis . The potassium bromide is used in the FTIR analysis in the 400-4000 cm - 1 range to produce a fine powder . [36]

2.4.6 Atomic force microscopy (AFM)

Atomic force microscopy (AFM) spectroscopy is a powerful tool for imaging , probing , and manipulating materials at the nanoscale . When it comes to silver oxide nanoparticles , AFM spectroscopy can provide significant insights into their structure , properties , and be havior . AFM classified as well as confirmed the size , shape , outside the region of produced Ag , O . [36]

2.4.7 Energy - dispersive X - ray spectroscopy (EDX)

EDX analysis , short for Energy - Dispersive X - ray Spectroscopy analysis , is an approach used to determine the sample's elemental composition . EDX analysis offers qualitative as well as semi - quanti tative information about the elemental composition of the sample . It can identify the presence of elements such as silver , oxygen , and any other elements that may be present as impurities or additives . The analysis can be used to verify the composition of the nanopar ticles and ensure that they are consistent with the intended silver oxide formulation . [37]

Chapter Three

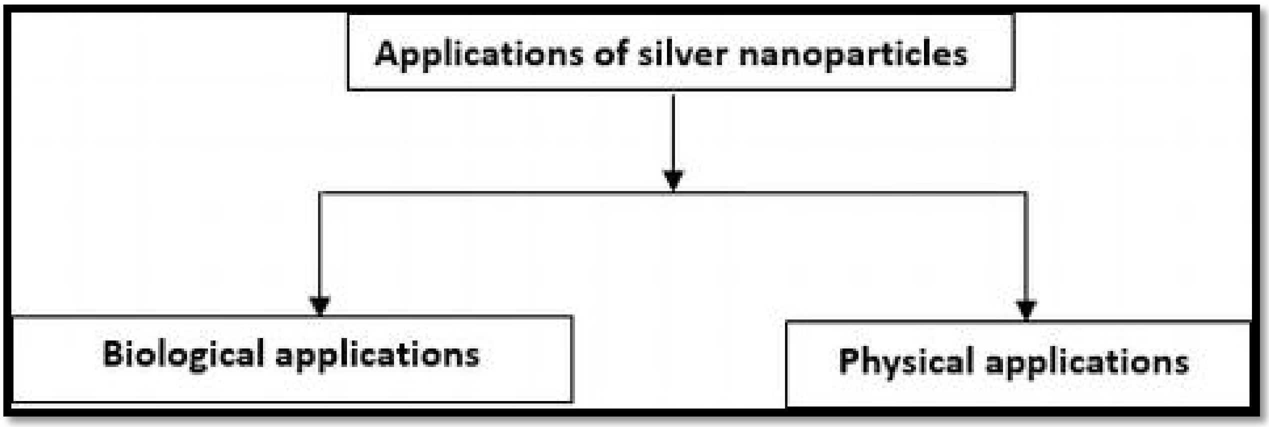
applications physical and biological

Chapter Three

applications physical and biological

3.1 Introduction

Applications of silver nanoparticles can be classified in two major classes, that is, therapeutic and physical applications (Figure 3-1).

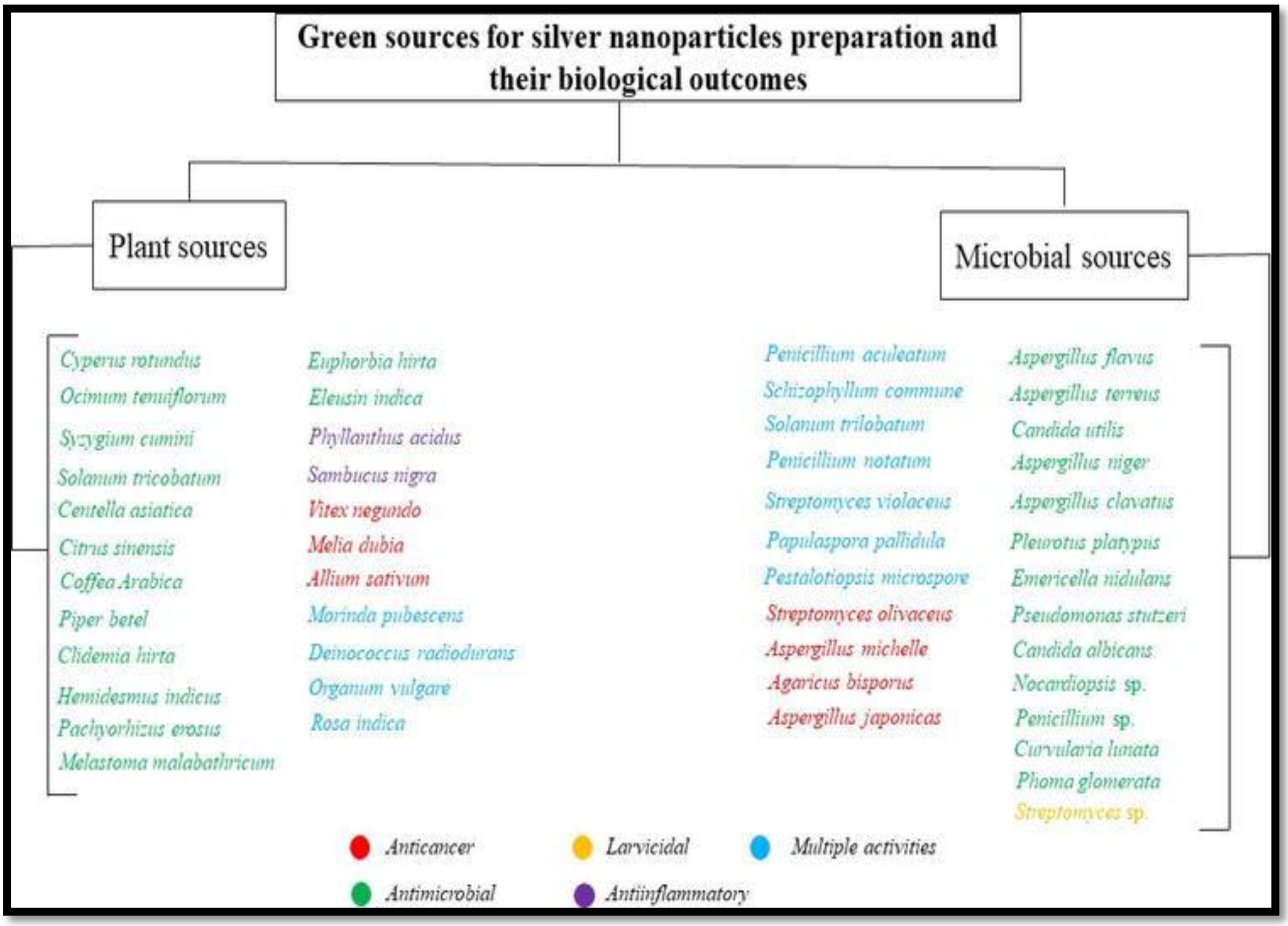


(Figure 3-1) Applications of silver nanoparticles. [38]

3.2 Biological applications

Silver nanoparticles have various biological applications (Figure 3-2) majorly antimicrobial, anticancer, antioxidant, anti-inflammatory, wound healing, antimalarial, etc. Inbathamiz et al. synthesized silver nanoparticles using aqueous extract of Morinda pubescens by reducing silver nitrate and evaluate them in vitro for their antioxidant (using DPPH, ferric thiocyanate, thiobarbituric acid, superoxide anion radical scavenging, H2O2, metal chelating, and phosphomolybdenum-like assay) and anticancer potential (by MTT assay on human epithelium cells of liver cancer (HepG2)). They found that silver nanoparticles have high antioxidant capacity as well as cytotoxic activity against HepG2 cell lines . [39]

Logeswari et al. synthesized silver nanoparticles using extracts of Ocimum tenuiflorum, Syzygium cumini, Solanum trilobatum, Centella asiatica, and Citrus sinensis from silver nitrate solution. Prepared silver nanoparticles were evaluated for antimicrobial activity against Staphylococcus aureus, Escherichia coli, Klebsiella pneumonia, and Pseudomonas aeruginosa using disk diffusion method. Results revealed that silver nanoparticles synthesized from Solanum trilobatum and Ocimum tenuiflorum possess the highest antimicrobial activity against Staphylococcus aureus (30 mm) and Escherichia coli (30 mm), respectively .[39]



(Figure 3-2) Natural sources used for preparation of silver nanoparticles and their biological potential. [40]

Most of the urinary tract infections are caused by Proteus mirabilis, Escherichia coli, Serratia marcescens, and Pseudomonas aeruginosa. These bacterial pathogens possess quorum sensing (QS) machinery to coordinate their cells and regulate several virulence factors as well as in biofilm formation. Srinivasan et al. prepared silver nanoparticles using Piper betle leaf extract from silver nitrate aqueous solution and evaluate them for anti-QS and antibiofilm potential. Results revealed that prepared silver nanoparticles were able to inhibit QS-mediated virulence factors such as protease, prodigiosin, biofilm formation, and exopolysaccharides as well as hydrophobicity productions in uropathogens. In vivo Caenorhabditis elegans assays also revealed their nontoxic and anti-adherence efficacy. Therefore, it was concluded that silver nanoparticles can be an effective alternative toward the conventional antibiotics in controlling QS and biofilm-related uropathogenic infections . [41]

Exopolysaccharide of the Streptomyces violaceus composed of total carbohydrate (61.4%), ash content (16.1%), and moisture content (1.8%) was efficiently used by Sivasankar et al. for synthesis of silver nanoparticles. Prepared silver nanoparticles were evaluated for antibacterial (against Pseudomonas aeruginosa, Escherichia coli, Staphylococcus aureus, and Bacillus subtilis) and antioxidant (using 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity, total antioxidant activity, H2O2 scavenging activity, nitric oxide scavenging activity, and ferric reducing power) activities. Results revealed that silver nanoparticles have promising antimicrobial and antioxidant activity . Salama et al. synthesized a series of nanocomposites based on chitosan biguanide-grafted poly(3-hydroxybutyrate) copolymer (ChG-g-PHB) and silver nanoparticles via in situ reduction of silver nitrate in copolymer matrix and evaluated them for antimicrobial activity against Streptococcus pneumonia, Escherichia coli, Salmonella typhi, and Aspergillus fumigatus. Results revealed that sample loaded with 3.0% silver nanoparticles has best antimicrobial activity (MIC 0.98–1.95 μg/ml) . Dried roasted Coffea Arabica seed extract was used by Dhand et al. for the synthesis of silver nanoparticles from silver nitrate and evaluated for antibacterial potential against Escherichia coli and Staphylococcus aureus; results confirmed the decrease in bacterial growth with well-defined inhibition zones . [42]

Boonkaew et al. developed a burn wound dressing that contains silver nanoparticles to treat infection in a 2-acrylamide-2-methylpropane sulfonic acid sodium salt (AMPSNa+) hydrogel and revealed that hydrogels were nontoxic to normal human dermal fibroblast cells as well as had good action against Pseudomonas aeruginosa and methicillin-resistant Staphylococcus aureus. They also revealed that 5 mm silver hydrogel was efficient in preventing bacterial colonization of wounds, and results were comparable to the commercially available silver dressings (Acticoat™, PolyMem Silver®). David et al. did an eco-friendly extracellular biosynthesis of silver nanoparticles using european black elderberry (Sambucus nigra) fruit extracts and evaluated them for their in vitro anti-inflammatory activity on HaCaT cells exposed to UVB radiation, in vivo on acute inflammation model, and in humans on psoriasis lesions. Results revealed that silver nanoparticles decrease cytokine production induced by UVB radiation and pre-administration of silver nanoparticles reduces edema and cytokine level in paw tissues after inflammation induction. They also demonstrate the possible use of silver nanoparticles in psoriasis lesions . [43]

Silver nanoparticles prepared by chemical reduction from aqueous solution ranged from 10 to 20 nm, and on antibacterial evaluation using Kirby-Bauer method, it was revealed that they have bactericidal activity against Escherichia coli, Pseudomonas aeruginosa, and Staphylococcus aureus . Kathiravan et al. synthesized silver nanoparticles using plant extract of Melia dubia and evaluated them against human breast cancer (KB) cell line. Results revealed that prepared silver nanoparticles had remarkable cytotoxicity against KB cell line with high therapeutic index . Latha et al. synthesized silver nanoparticles using leaf extract of Hemidesmus indicus and evaluated them for antibacterial activity against the isolated bacteria Shigella sonneiusing agar bioassay, well diffusion assay, and confocal laser scanning microscopy (CLSM) assay. Results revealed that silver nanoparticles have higher inhibitory activity (34 mm) at 40 μg/ml . [44]

Ramar et al. synthesized silver nanoparticles using ethanolic extract of rose (Rosa indica) petals and evaluated them for their antibacterial activity against selective human pathogenic microbes and anticancer activity against human colon adenocarcinoma cancer cell line HCT-15. Results revealed that silver nanoparticles were effective against Escherichia coli, Klebsiella pneumonia, Streptococcus mutans, and Enterococcus faecalis. The MTT assay, nuclear morphology analysis, mRNA expression of Bcl-2, and Bax and protein expression of caspase 3 as well as caspase 9 indicate the potential anticancer activity . Manikandan et al. prepared silver nanoparticles using aqueous extract of Phyllanthus acidus fruits from aqueous silver nitrate solution and investigate their possible role in cytoprotection and anti-inflammation. [45] They find that silver nanoparticles possess potent anti-inflammatory activity by scavenging nitric oxide and superoxide anions . Syafiuddin et al. The silver ions were reduced to silver nanoparticles by using biochemical contents present within Cyperus rotundus, Eleusin indica, Melastoma malabathricum, Euphorbia hirta, Clidemia hirta, and Pachyrhizus erosus extracts. Prepared silver nanoparticles were evaluated for antibacterial capability against E. coli, B. cereus, and rare bacterium Chromobacterium haemolyticum. They found that all silver nanoparticles have antibacterial capability . Pandian et al. synthesized silver nanoparticles using Allium sativum extract and evaluated by cytotoxic assays. Surprisingly, prepared silver nanoparticles have enhanced cytotoxic effect and induced many apoptotic cells even with lower concentrations. However, silver nanoparticles are cytotoxic to normal cell line (VERO cells) at higher concentrations, but careful use with lower concentrations can make silver nanoparticles an efficient anticancer agent . [46]

Prabhu et al. synthesized silver nanoparticles using leaf extract of Vitex negundo as a potential antitumor agent using human colon cancer cell line HCT15. Silver nanoparticles were able to arrest HCT-15 cells at G0/G1 and G2/M phases with a decrease in S phase. Results suggest that silver nanoparticles may exert their antiproliferative effect on colon cancer cell line by suppressing its growth, reducing DNA synthesis, arresting G0/G1 phase, and inducing apoptosis . Silver nanoparticles were synthesized by Ramar et al. using unripe fruit extract of Solanum trilobatum and evaluated for antibacterial activity against few human pathogenic bacteria (Streptococcus mutans, Enterococcus faecalis, Escherichia coli, and Klebsiella pneumonia) as well as anticancer activity against human breast cancer cell line (MCF-7) using MTT, nuclear morphology assay, Western blot, and RT-PCR expression. Results revealed that prepared silver nanoparticles have potential antibacterial and anticancer activities . [46]

Silver nanoparticles were evaluated for their effect on growth and health of broiler chickens after infection with Campylobacter jejuni, and results revealed that concentration of 50 ppm in drinking water reduces broiler growth and impairs immune functions while having no any antibacterial effect .

Sankar et al. prepared silver nanoparticles using the aqueous extract of Origanum vulgare by reducing 1 mm silver nitrate solution. They evaluated prepared silver nanoparticles for antibacterial and anticancer efficacy. [47]

Silver nanoparticles were found to have an impressive inhibiting effect on human pathogens (Aeromonas hydrophila, Bacillus spp., Escherichia coli, (enteropathogenic—EP), Klebsiella spp. Salmonella spp., Salmonella paratyphi, Shigella dysenteriae, and Shigella sonnei) as well as a cytotoxic effect against human lung cancer A549 cell line . Sun et al. prepared fabricated silver nanoparticles combined with quercetin, which were stabilized by using a layer of molecules, that is, siRNA, and found that the prepared silver nanoparticles have potential activity against B. subtilis . Li et al. synthesized silver nanoparticles by reduction of aqueous silver ion with culture supernatants of Aspergillus terreus, and prepared silver nanoparticles showed excellent antimicrobial activity against Candida albicans, Candida krusei, Candida parapsilosis, Candida tropicalis, Aspergillus flavus, Aspergillus fumigatus, Staphylococcus aureus, Pseudomonas aeruginosa, and Escherichia coli . [48]

3.3 Physical applications

3.3.1 Fabrication of antennas

Alshehri et al. have prepared two samples: the first was fabricated from the nano-metallic silver, and the second consists of micrometer-sized grains. Both types were prepared using thick-film fabrication process. The material involved in sample preparation was fine metal powder, an inorganic binder-like metal oxide, and an organic vehicle that evaporates during the initial drying stages. Both the samples were characterized for the electrical performances. They found that in the lower-frequency range, both types of conductors (samples) behave similarly with electrical loss but increase approximately linearly with increased frequency range (from 0.1 dB/mm/GHz up to 80 GHz), but above 80 GHz frequency, the silver nanoparticle-fabricated sample showed lower electrical loss, and this behavior continues up to the above whole frequency range. [49]

The lower level of the loss from the silver nanoparticle conductors and the overall trend in loss per wavelength do not depend significantly on frequency. Therefore, it has been concluded that the silver nanoparticle-fabricated conductors show a less electrical loss at high-frequency range which in turn attributed to lower surface roughness found in the nanoparticles due to better packing and may open opportunities for low-temperature fabrication of antennas and for sub-THz metamaterials with improved performance . [49]

3.3.2 In electronically conductive adhesives

Silver nanoparticles can be used as a silver paste in the electrodes because of their high conductivity. They have also been used as conductive fillers in electronically conductive adhesives (ECAs). Chen et al. have synthesized the silver nanoparticles by reducing the silver nitrate with ethanol in the presence of polyvinylpyrrolidone (PVP). Various reaction conditions have been studied such as PVP concentration, reaction time, and reaction temperature. In this method, PVP prevents the aggregation; in addition to this, the PVP increases the rate of spontaneous nucleation and decreases the mean size of silver nanoparticles. The ethanol used in this has been employed as a reducing agent or diluent to adjust the viscosity of the ECAs. [50]

The resulting silver nanoparticles obtained with chemical reduction method had very fine dispersion and narrow size distribution. The ECAs had the silver nanoparticles re-dispersed in the ethanol. The absorption peak was determined at 410 nm which was a clear signature of the quantum size effect occurring in the absorption property of silver nanoparticles. It has also been concluded that the particle size of nanoparticles has been decreased with increasing concentration of silver nitrate and with increasing reaction temperature, but with increasing reaction time, the size of nanoparticles has been increased . [51]

Yang et al. have prepared silver nanoparticles, silver nanorods, and epoxy resins containing high-performance electrically conductive adhesives (ECAs) using a novel preparation method. The prepared nanoparticles and nanorods were dispersed well, and there was no agglomerate in the matrix. The volume electrical resistivity tests showed the volume electrical resistivity of the ECA was closely related with the various sintering temperatures and time and time and the ECA could achieve the volume electrical resistivity of (3–4) × 9 10–5 Ω after sintering at 160°C for 20 min. They found that the prepared ECA was able to achieve low-temperature sintering and possessed excellent electrical, thermal, and mechanical properties . This offers the possibility to effectively use these synthesized nanoparticles for improving the conductivity of ECAs .[52]

3.3.3 Ink-jet printing

The silver nanoparticles can be used in ink-jet printing. Wu and Hsu have synthesized the silver nanoparticles by chemical reduction from the silver nitrate using triethylamine as reducing and protecting agent. After that the nanoparticles have been sintered using the process involved cleaning it with acetone and deionized water to remove the particles and organic contaminants on the surface; after cleaning the film, it was treated with ozone by UVO-100 UV ozone for 30 min. [52]

The silver nanoparticle suspensions were spin coated (500 rpm, 15 s) on the polyimide substrate and dried at room temperature in order to remove the solvent. The resulting silver nanoparticles on the polyimide substrate were heated from 100 to 200°C and held at 200°C for 1 h in order to convert to silver films. The polyimide substrate was then naturally cooled at room temperature in the glass dish. The above synthesized silver nanoparticles were sintered at different temperatures, and it was found that the resistivity of the silver film sintered at 150°C for 1 h was close to the resistivity of bulk silver. Based on the above data, the synthesized nanoparticles had the low sintering temperature; hence, the silver nanoparticle suspensions could be used to fabricate the flexible electronics by ink-jet printing . [53]

3.3.4 Fillers

The micro-sized silver particle fillers appear as the full-density silver flakes, and the silver nanoparticles fillers appear to be the highly porous agglomerates (similar to open-cell foams). Ye measured/analyzed the distribution of different sized particles using TEM. The electrical resistivity was also measured which was compared with the different levels of filler loading. The silver nanoparticles were prepared using the nano-sized spheres of size approximately 50–150 nm in diameter, micro-sized particles with a diameter of 5–8 μm, and flakes of silver of 10 μm in length. By TEM studies of the distribution of silver particles in micro-sized particle sea, it was concluded that it is difficult to find the cross-linkage of particles and there are fewer chances of different contact and contact area, and by the resistivity measurements, it has been revealed that the conductivity of micro-sized silver particle-filled adhesive is dominated by constriction resistance, the silver nanoparticle-containing adhesive is controlled by tunneling and even thermionic emission, and hence the respective nanoparticles are used to increase the electrical conductivity . [54]

3.3.5 Water treatment

Dankovich prepared silver nanoparticles in a paper using microwave irradiation. Antibacterial activity and silver release from the silver nanoparticle sheets were assessed for model Escherichia coli and Enterococcus faecalis bacteria in deionized water and in suspensions that also contained with various influent solution chemistries, that is, with natural organic matter, salts, and proteins. The paper sheets containing silver nanoparticles were effective in inactivating the test bacteria as they passed through the paper. The resultant silver nanoparticle paper is just as effective for inactivating bacteria during percolation through the sheet; the silver nanoparticle papers effectively purify water contaminated with bacteria. Hence, in conclusion, the paper incorporated with silver nanoparticles by microwave has been used for the purification of contaminated water . [55]

Park et al. developed micrometer-sized silica hybrid composite decorated with silver nanoparticles, that is, AgNP-SiO2 (to prevent the inherent aggregation of silver nanoparticles and easy recovery from environmental media after utilization), and evaluated them for antiviral activity using bacteriophage MS2 and murine norovirus (MNV) models. Results revealed their potential, and it was concluded that developed silver nanoparticles (AgNP-SiO2) can be efficiently used in disinfection processes for inactivation of various waterborne viruses . [56]

Abu-Elala et al. investigated the effect of chitosan-silver nanocomposite on fish crustacean parasite, Lernaea cyprinacea, disease found in goldfish (Carassius auratus) aquaria during the spring season. Their results proposed that chitosan silver nanocomposite is efficient in parasitic control in ornamental glass aquaria.

3.3.6 Solar cell optimization

Plasmonic effects in thin film silicon solar cell are an emerging technology and area of rigorous research for the researchers from the past couple of years. It has promising application in solar cell fabrication industries where it uses nanoscale properties of silver nanoparticles incorporated in the interface between the metal and dielectric contacts that enhance the light-trapping properties of thin film silicon solar cells by increase absorbance capacity and generation of hot electrons that enhance the photocurrents in the solar cell. Sangno et al. had taken two different thicknesses of the silver thin film (made of silver nanoparticles) of 5.9 and 7.8 nm in 2×10^{-4} (Torr) and 2.5×10^{-4} (Torr) pressure environment for investigation purpose. Samples were annealed at different temperature ranges for a definite time period under vacuum condition of 4.5×10^{-6} Torr. They found that reflectance reduces 13–11% due to plasmonic effect and enhancement in the conversion efficiency of the solar cell . [56]

3.3.7 Biosensor fabrication

Li et al. fabricated nanoenzymatic glucose biosensors by depositing silver nanoparticles using in situ chemical reduction method on TiO_2 nanotubes which were synthesized by the anodic oxidation process. The structure, morphology, and mechanical behaviors of the electrode were examined by scanning electron microscopy and nanoindentation. It was found that silver nanoparticles remained both inside and outside of TiO_2 nanotubes whose length and diameter were about 1.2 μm and 120 nm. The composition was constructed as an electrode of a nonenzymatic biosensor for glucose oxidation. The electrocatalytic properties of the prepared electrodes for glucose oxidation were investigated by cyclic voltammetry (CVs) and differential pulse voltammetry (DPV). When compared with bare TiO_2 and silver-fresh TiO_2 nanotube, Ag-TiO_2/(500°C) nanotube exhibited the best electrochemical properties from cyclic voltammetry (CVs) results. In addition, the nonenzymatic glucose sensors exhibited excellent selectivity, stability, and repeatability. Nanoenzymatic glucose biosensors have potential application in catalysis and sensor areas . [57]

Ruth et al. has synthesized the oligonucleotide-silver nanoparticle (OSN) conjugates and revealed their use with magnetic beads as a biosensor for Escherichia coli detection under the magnetic field condition. The biosensor developed was able to detect the presence of DNA target which was isolated from the three isolation methods, and it has been found that best detection signals were achieved by the isolation method in which it could detect the presence of DNA target up to 1.3 ng/μl . [57]

Mahmudin et al. synthesize the silver nanoparticles by chemical reduction method. TEM images showed that morphology of silver nanoparticles had spherical geometry and had dispersive particle distribution. They conclude that this type of dispersibility of nanoparticles such as this could potentially be used as an active ingredient of SPR biosensor . Sistani et al. have developed the enzymatic biosensor for selective detection of penicillin by using silver nanoparticles, and sensor configuration showed the linear dynamic range for output response vs. logarithmic concentration of a salt solution of penicillin . [58]

3.3.8 Protein sensing

Tung N.H reported that silver nanoparticles labeling could be used in protein sensing studies by liquid electrode plasma-atomic emission spectrometry (LEP-AES). This technique is suitable for on-site portable analysis because plasma gas and the high-power source are not required. Proposed detection method could have a wide variety of promising applications in metal nanoparticle-labeled biomolecule detection . [59]

3.3.9 Hospitals

Duran et al. prepared silver nanoparticles by using Fusarium oxysporum and studied their antimicrobial effect when incorporated in cotton fabrics against Staphylococcus aureus. They found that fabric incorporated with silver nanoparticles have significant antibacterial activity. [60] They proposed that clothes with silver nanoparticles are sterile and can be useful in hospitals to prevent or to minimize infection with pathogenic bacteria such as Staphylococcus aureus .

3.3.10 Analytical

Lipids are the major components of cell membrane and abnormal cellular metabolism-induced lipid changes. Hua et al. investigate silver nanoparticle-induced lipid changes on the surface of macrophage cells using time-of-flight secondary ion mass spectrometry (ToF-SIMS). By using this technique, one can understand the mechanism of cell-nanoparticle interactions at the molecular level and characterize the changes in lipids on the single cell surface . [61]

Citrate- and polyethyleneimine-coated silver nanoparticles can be used to understand how the type of capping agents and surface charge affects their colloidal stability, dissolution, and ecotoxicity in the absence/presence of Pony Lake fulvic acid (PLFA). On the basis of this, Jung et al. demonstrate that the differences in colloidal stability, ecotoxicity, and dissolution may be attributed to different capping agents, surface charge, and natural organic matter concentration as well as to the formation of dissolved silver complexes with natural organic matter . [62]

3.3.11 Agricultural and marine

Silver nanoparticles synthesized by Guilger et al. using fungus Trichoderma harzianum were evaluated for cytotoxicity and genotoxicity against fungus Sclerotinia sclerotiorum which is responsible for the agricultural disease white mold and found that nanoparticles showed potential against Sclerotinia sclerotiorum, inhibiting sclerotium germination and mycelial growth. The study suggests that silver nanoparticles can be a new alternative in white mold control. Babu et al. have synthesized silver nanoparticles in vitro using marine bacteria Shewanella algae bangaramma and found that the synthesized nanoparticles have both larvicidal and bactericidal activities and no mortality in control; in addition to this, the maximum values of LC50 and LC90 with 95% confidential limit [4.529 mg/ml (2.478–5.911), 9.580 mg/ml (7.528–14.541)] were observed with third instar larvae of Lepidiota mansueta (Burmeister). [63]

It was found that the mortality of larvae was significantly increased in all the concentrations ($P < 0.0001$) in all the exposed groups. The bactericidal activities of the silver nanoparticles were determined against some of the bacterial species which followed the following order: Vibrio cholera , Roseobacter spp. Alteromanas spp. It has been concluded that the synthesized silver nanoparticles had effective larvicidal and antifouling activities and can be effectively used in the agricultural and marine pest control . [63]

Conclusion

It is revealed that silver nanoparticles have potential applications in therapeutics as well as in other physical fields. In therapeutics, researchers are seemed to be more focused on anticancer and antimicrobial evaluations. Green synthesis makes them eco-friendly and nonhazardous. Applications of silver nanoparticles are not limited to therapeutics only, they are equally covering physical fields too such as biosensors and antenna fabrication, conductive adhesives, in ink-jet printing, water treatment, solar cell optimization, protein sensing, etc. Rigorous research has been carried out and continued on this nanostructure. Therefore, the silver nanoparticle has the ability to be a lead nanoparticle of the future due to its wide variety of applications.

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