Chapter 4

Synthesis, Characterization and Antimicrobial Properties of Silver Nanocomposites

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Additional information is available at the end of the chapter

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Abstract

Nanoparticles and polymers in their respective fields have contributed greatly in the form of science and hence in daily life application products. But due to lack in emerging technologies for developing silver nanocomposites with polymers and other materials, the nanoparticle-based products have conquered little less attention. Hereby, an effort is made to put a light on already developed functional materials containing silver nanoparticles and also to look forward their scope in daily life applications. A little more insight into antimicrobial properties of such materials will also be elaborated. Finally, the optimal amounts of silver that cannot be health hazardous to living being especially human and overall environmental impacts of Nanocomposites are presented.

Keywords: silver nanoparticles, functional materials, antimicrobial properties, polymers

1. Introduction

Today the nanoscience can easily be presumed as the key feature of modern world technology. Thereforth, due to assorted field of utilizations, it is playing pivotal role in material science industry [1]. Its applications can monetarily expand the properties and estimations of material preparing and items. The nanomaterials are prepared either by incorporating into the core matrix of the material or via polishing over the surface of designed materials. The wide spread application of nanomaterials ranges from catalysis to electronics and optics as well as in magnetics alongside the health and environment applications [2]. Yet the future of nanotechnology in material applications lies in territories where the new standards will be joined into strong, multifunctional material frameworks without bartering the intrinsic material properties.

Silver nanoparticles are domineering among the most important and entrancing nanomaterials among a few metallic nanoparticles that are engaged with the biomedical applications. They exhibit excellent antibacterial, antifungal, anti-inflammatory and antiviral properties generously or either after reacting with specific elements to impart such functional properties [3]. To an extent, the silver nanoparticles can be utilized against a broad variety of infections [4]. The use of silver nanoparticles is not restricted to the medical field only; they have been also used as self-cleaning, UV protection, improving durability and opto-electronics.

Silver is stable in pure water and air environments but the surrounding of ozone, hydrogen sulfide or sulfur if present in air or water may bring about silver tarnishing because of the formation of silver sulfide [5]. Apart from conventional Ag^+, silver is available in three other oxidation states: Ag^0, Ag^{2+}, Ag^{3+}. However, the last two are unstable and rarely found in the sea-going condition. Silver has numerous isotopes but with molecular weight 107 is the most commonly existing. Even though intense poisonous quality of silver in the condition is subject to the accessibility of free silver particles, analyses have appeared that these convergences of Ag^+ particles are too low to lead toxicity. Metallic silver appears to posture the negligible hazard to wellbeing, while solvent silver mixes are all the more promptly consumed and can possibly deliver unfriendly effects [6]. The decrease in the measure of silver to nano-sized silver expands its capacity to control microscopic organisms and growths. Because of the extensive surface region of nanomaterials prompt the expanded contact with microbes and growths which builds its affectivity. Nano-silver, when in contact with microorganisms and their growth, unfavorably influences the cell digestion of the electron exchange structures

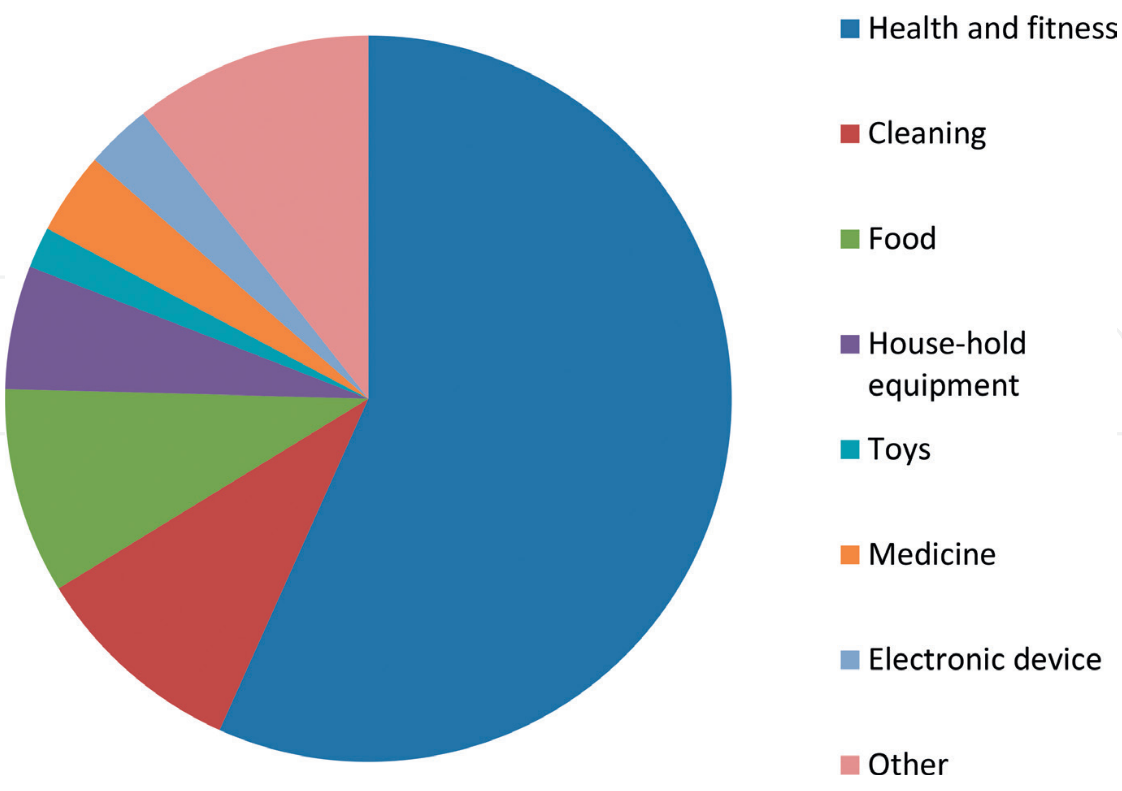

Figure 1. Application of silver nanoparticles in different fields.

and cause the substrate movement in the microbial cell film [7]. Microscopic organisms and growths causes irritation, contamination, smell, wounds, the utilization of nano-silver subdue the expansion of microscopic organisms and parasites [8]. Nano-silver have been generally utilized because of its antibacterial microbial movement for the advancement of items containing silver incorporate nourishment contact materials, (for example, containers, bowls and cutting sheets), scent safe materials, gadgets and family unit apparatuses, beautifying agents and individual care items, therapeutic gadgets, water disinfectants, room splashes, children's toys, newborn child items and health supplement [9] (**Figure 1**).

2. Synthesis of silver nanoparticles

The nanoparticles of silver can be synthesized by various physical, chemical, biological and other methods. The most prevalent chemical methodologies contain the chemical reduction by using a range of several inorganic and organic reducing agents, physicochemical reduction, radiolysis and electrochemical methods [10]. The vast majority of these techniques are still in the development stage as well experienced some complications in silver nanoparticles stability and accumulation, morphology, size and size distribution [11]. Moreover, for the produced silver nanoparticles, the extraction and purification are still significant concerns for further applications. Besides, silver nanoparticles prepared through biological-, irradiation- and Tollen's method and in presence of polyoxomerales and polysaccharides method can also be incorporated into functional materials [12].

In the biological method, the synthesis of silver nanoparticles takes place through the reduction of the silver ion by the help microorganisms extracts [13]. The extracts of the microorganisms at a time can behave as both the capping agents as well as reducing agent. The preparation of silver nanoparticles by using polysaccharides along with water as the capping agent is recognized as polysaccharide technique [14]. The nanoparticles of silver can also be synthesized by using numerous irradiation methods like UV-irradiation, microwave, gamma rays and through sonochemical methods [15]. These nanoparticles can also fabricated by the Tollen's method and polyoxomerales procedures. The stable spherical silver nanoparticles with a diameter 0.5–150 nm are also created at the several concentration of silver nitrate using the biosynthesis procedure [16]. These methods have many advantages than chemical, physical and the microbial synthesis because in this procedure no hazardous chemicals are being used. Fundamentally, the green synthesis is considered to be an environmental friendly as well the cost effective substitute to the physical and chemical procedures.

The plant extract is the most common reducing agent in the green synthesis [17]. Generally, the silver ions face reduction in aqueous solution to produce different nanometer diameter sized colloidal silver. Herein, the silver ions also get reduced to silver atoms which then rise into the oligomer clusters. Later these clusters support to advance the colloidal silver particles. Fabrication of silver nanoparticles follows the three chief principles that are, the selection of solvent medium, and selection of environment friendly reducing agent along with the choice of the harmless substances to stabilize the nanoparticles of silver. A huge collection of secondary metabolites is created in plants that have the redox capability for the biosynthesis of silver nanoparticles. So, the silver nanoparticles are produced from Ag+ ion by the bio reduction by the help of plant metabolites [18]. The uniform silver nanoparticles of controlled size can also be synthesized by using the microemulsion procedures [19]. The nanoparticles preparation in the two-phase aqueous organic schemes is centered onto the preliminary spatial split-up of the reactants of metal precursor and reducing agent into the two immiscible segments. The interface between the two fluids and the strength of inter-phase transference between the two phases, which is intermediated by the quaternary alkyl-ammonium salt, influence the level of interactions between the metal precursors and the reducing agents. The metal clusters formed at the interface are stabilized, due to their coated surface with stabilizer molecules arising in the non-polar aqueous medium, and shifted to the organic medium by the inter-phase transporter [20]. The major drawbacks of this process are the use of highly poisonous organic solvents. Consequently, the large amounts of surfactant and the organic solvent must be disconnected and removed from the final product. On the other hand, the colloidal nanoparticles prepared in no aqueous media for conductive inks are well-dispersed in a low vapor pressure organic solvent, to readily wet the surface of polymeric substrate without any accumulation [21].

The nanoparticles of silver can be produced through the wide range of the irradiation methods [22]. The silver nanoparticles of well-defined shape and size can be produced by the laser irradiation of the surfactant along with an aqueous solution of the silver salt. Moreover, laser is being used in the photo-sensitization synthetic method of producing the silver nanoparticles by using benzo-phenone. At the short irradiation periods, the low laser powers formed the nanoparticles of about 20 nm, whereas an improved irradiation power created the silver nanoparticles of the size about 5 nm. Mercury lamp and laser can be used as the light sources for the production of the silver nanoparticles. In the visible light irradiation method, the photo-sensitized growth of silver nanoparticles using thiophene (sensitizing dye) and silver nanoparticle formation by illumination of [Ag(NH3)]+ in ethanol are being used [23].

Among all available methods, the basic route for the syntheses of nanoparticles is defined by keeping in mind the parameters like availability of chemicals, natural extract and available instruments, the demanded size and shape of nanoparticles and most importantly the use of nanoparticles in a particular application. In our laboratory, we prepared the solvent-free synthesis of oleophlic nanoparticles from silver nitrate and oleyl amine [24]. The direct heating of reaction mixture for 20 min at 165°C yielded the nanoparticles of average 68 nm upon dispersal in ethanol. The ultra-refined nanoparticles were incorporated in the polymerization of dicyclopentadiene and polymers were evaluated against their activity for microbes. Another example constitutes the manufacturing of fluff pulp using sonochemically impregnated silver nanoparticle and the materials was compared for their antimicrobial properties against the conventionally used sodium borohydride reducing agent [16].

3. Application of silver nanoparticles in functional materials

Silver nanoparticles represent the manifest nano-products and are now generally utilized as a part of medicinal applications, including wound dressing, diagnosis, water filtration, electronics, optics, and pharmacological treatment [15]. Since the shape, size, and synthesis of silver nanoparticles can affect their capability and conceivable dangers to human wellbeing, broad research is expected to completely comprehend their amalgamation, portrayal, and conceivable harmfulness. Herein, we present an outline of silver nanoparticles amalgamated materials for utilizations in different fields.

Nano-silver has high electrical and thermal conductivity alongside the improved optical properties that prompts different applications in hardware. In nano-electronics, silver nanowires are utilized as nano-connectors and electrodes. Other applications include opto-electronics, nano-electronics, (for example, single-electron transistors and electrical connectors), information stockpiling gadgets, the readiness of dynamic waveguides in optical gadgets high thickness recording gadgets, intercalation materials for batteries, making small scale interconnects in coordinated circuits (IC) and fundamental capacitors [25].

For the access of clean water, a feasible treatment of the combination of filtration along with disinfection is recommended. Revealing in Nanotechnology, analysts have built up a layer channel in view of silver nanostructures that are connected to cellulose filaments. Driven by gravity, the framework gives a rapid yet modest and sturdy alternative for the cleansing of water [26]. The silver nanostructures gradually break down and discharge silver particles, which have been utilized as antibacterial operators for a considerable length of time. In such a way, debased water can be purged averting basic sicknesses, for example, cholera or gastroenteritis. This gives a shabby, protected, compact and simple to-utilize water-purification framework.

Similarly, it is equally utilized with conjunction of copper ions as a protection measured against colonization of Legionella spp. Silver nanoparticles are right now being tried in various trial purpose of-utilization (POU) treatment frameworks and ionic silver has been researched for its potential use as an optional disinfectant (to lessen levels of chlorine) in drinking-water supplies. Silver particles (in mix with both copper and chlorine) have also been examined for use in swimming pool sterilization [27].

The production of metal-polymer involves multiple procedures. Due to harmful steps and difficulty in managing the nanoparticles for even distribution in the large medium, less work has been done using ex-situ process. Besides this, in-situ method has been appreciated for linking the beneficial properties of all the materials involving in the process and metal NPs formed through it has provided numerous uses. According to the latest research study, different polymer amalgams have been tried for fabrication of metal nanoparticles. The technique of in-situ method in polymer matrixes majorly deals with uniform solution, direct photo-reduction and photo-sensitization [28]. Basically photo-reduction of the metal and reduction of their salts/ions takes place to generate M^0. The main approach for synthesis of the Ag nanoparticles involves the reaction between silver cations and shortly lived specie formed by photo-generation. Two photo-induction reactions are performed to formulation the basic radicals.

Another process involves the photo-initiation by acryl-phosphine (photo-initiator) that encourages the synthesis of silver nanoparticles by the reduction of $AgNO_3$ and fundamental polymerization of acrylic resin. Hence, speedy production of metallic silver and radical initiation of the crosslinking polymerization takes place at the same time when irradiation of Irgacure 819 is reacted with polyethylene-glycol di-acrylate monomer in the presence of $AgNO_3$. Change in color of the solution was observed by the UV-Visible absorption that clarifies the synthesis of silver nanoparticles [29].

A wide range of actinic wavelengths and photo- reduction media were tried for fabrication of silver nanoparticles through photo-induction method. **Table 1** describes the photo-indicator and their chemical structures that have been tried for this respective purpose. In another example, by mixing of silver cations and dye, two processes i.e.; photo-reduction and photo-initiation are simultaneously carried out. Ag nanoparticles were uniformly dispersed in the polymer mixture and photo-polymerization process was carried without any interruption. This single step process for synthesis of silver nanoparticles proves to be new method for production in polymer matrixes. Apart from the synthesis of nanoparticles in spherical form by photo-induced method, the production of the NPs in other distinctive geometrics is thought-provoking matter still left for working [30].

Among the numerous conductive materials like; nickel, palladium, gold, copper, graphite, silver, and carbon fibers, only silver exhibits the best properties due to its brilliant conductivity as well chemical durability and also ability to manufacture the different shapes of the nanostructures with modified substrates. For increasing the conductivity, a ribbon shaped silver nanostructures is formed by the fabrication of the metallic ribbons where the cotton fabric is being used as a substrate. By these techniques a solution of a solution of PVP and $AgNO_3$ in ethylene-glycol (EG) is sprayed onto the cotton fabric surface and dried at about 160±5°C for 8 min [31]. The nano-porous structure of cotton can act as a nano-reactor and hence a good pattern to control the shape of nano-structure is produced. These ribbons are further characterized by SEM micrographs. Therefore, the technique provides a geometrically organized method to synthesize in-situ nanoribbons onto the fabric models [32].

The conducting polyaniline produced in the existence of the oxidizing agent potassium dichromate by the chemical oxidation process helped in producing silver composites using various compositions of silver nitrate ($AgNO_3$) into the polyaniline. The surface morphology of the composites was investigated utilizing Scanning electron magnifying instrument (SEM) demonstrate that Ag molecule are implanted in the chain of polyaniline to form the different phases. The powder X-beam diffraction (XRD), Spectrograph recommends the semi-crystalline behavior of the materials. It was additionally discovered that the electrical conductivity of PANI/Ag nanocomposite was around 100 times higher than that of the pure polyaniline. The arrangement of PANI as the semiconducting polymer with the silver as the noble metal can

Dentistry	The silver-loaded SiO_2 nanocomposite resin filler used as an additive in the polymerizable dental constituents
Neurosurgery	The coating of the catheter for the drainage of cerebrospinal fluid
Eye care	Nano-silver used in the coating of contact lenses
Anesthesiology	Used in the coating of the breathing mask also in endotracheal tube for the mechanical ventilatory maintenance
Diagnostics	Nano-silver pyramids for improved bio-detection Ultrasensitive and ultrafast stage for clinical tests for analysis of myocardial localized necrosis Fluorescence-based RNA detecting Magnetic center/shell Fe_3O_4/Au/Ag nanoparticles with turnable plasmonic properties

Table 1. Coatings of silver nanoparticles in different medical domains.

produce the hybrid material which behaves as the semiconductor at the low temperature and as the metal at relatively high temperatures [33].

Polyvinylpyrolidone is one of the largest contributors for polymer based nanoparticle synthesis. In a particular example, silver nanoparticles- polyvinylpyrolidone (PVP) composite comprising the 100 ppm of silver has been synthesized in the powder in the textile applications by utilizing the sonochemical method comprising the sonication and reduction with the tri-sodium citrate followed by the spray drying. The synthesized PVP coated silver nano-powder is characterized by using the atomic absorption spectra, UV-visible spectra, energy dispersion analysis of X-ray and transmission electron microscope. As well the EDX measurements confirm the presence of silver in the synthesized powder. The silver nanoparticles of the size of 50–60nm are present in the nano-powder. By exhaustion method, silver nano-powder can be applied onto the cotton and wool fabric for imparting the antibacterial efficacy. A clear zone of inhibition was observed in both of the treated cotton and wool fabrics against the microorganisms [34].

Nano-silver is being utilized in paper industry by DocuGuard and many others. The use of silver nanoparticle-based paper for the protection of the hospital case notes as well the medical files against the production of bacteria. Future applications include the business stationery, brochures, envelopes, as well the book-binding materials. Nano-silver can be used in the commercial water-purification schemes where polymers and fibers containing silver nanoparticle for stronger antimicrobial applications. Due to such antibacterial properties, nano-silver is also being used in the interior of the automobiles such as steering wheels and in building materials such as sanitary tubing and coverings. Nano-silver can also be used for the preservation of wood to resist mold and mildew. MTR Corporation in Hong Kong reports the use of silver nanoparticles in combination with titanium dioxide coating to improve the hygiene by spraying it onto the surfaces in MTR train stations, inside train compartments, as well as MTR managed shopping malls, staff offices along with recreational services [35].

The accumulation of the coated silver nanoparticles to the matrix of polypropylene by the extrusion process signifies a stimulating solution that increases the protection against the bacteria of both nature Gram-negative like *S. aureus* and Gram-positive like *E. coli*. Some of the silver nanoparticles disclosed inside the Polypropylene film which obstructs the antibacterial activity however the general outcome was the high antibacterial effectiveness. Typical organic biocides have limited their applications due to low heat resistance, high decomposability, short life and high toxicity. One feasible alternative are inorganic biocides such as polymers composites. Presence of silver nanoparticles also slightly increases the thermal stability of PP-AgNPs (Polypropylene-silver nanoparticles) compounds therefore assisting the easy processing; this could be done to the interaction between polypropylene chains and (PVP) surfactant-coated silver nanoparticles. Reduction (%) CFU assay exhibited positive biocide outcomes for *S. aureus* and for *E. coli* bacteria. No cytotoxicity effect is produced onto the polypropylene film having silver nanoparticles (AgNPs) [36].

Water soluble biopolymers in combination with AgNP were expected to produce new antimicrobial activities. A stream of natural polymers has been employed for the preparation process of polymeric AgNP nanocomposites. Polyvinyl alcohol (PVA) represent a nontoxic, synthetic and water soluble polymer used in stabilization in nanoparticles synthesis and their blend with chitosan exhibits antimicrobial activity against pathogenic bacteria in food packaging preparation. Films of AgNPs/PVA/CS were synthesized using solution casting method. Solutions of equal weights of PVA and CS were prepared using double distilled water with constant stirring at 60°C. The homogeneous solution was casted into Petri dishes and left to dry at 50°C for 3 days to form the desired film with a thickness from about 0.5–1.0 mm, and then the films were stripped off the dish. After the FTIR and XRD analysis, the results indicate that the nanocomposite samples show better film properties than that of pristine polymer blend without silver nanoparticles [37].

4. Application of nanotechnology in textiles

Nanotechnology has appeared to be the paramount technology for the abundant applications that could cover an extensive range of the industries [3]. The increased efficiency has subsequently added the definite value of products in textile industry. Development of the smart, nano-textiles has the great potential to revolutionize the production of the fibers, nonwovens or woven fabrics and functionality of the clothing in all forms of the textile products [38]. Silver nanoparticles are being widely used in apparel applications that include a wide range of functional properties. The fabrics containing engineered nano-silver are also being used to kill odor causing bacteria in socks and sports clothing.

The nano-fibers of silver are of the great importance recently in view of the double advantages from silver particles and nano-fibers. Silver nanoparticles are widely utilized for biomedical applications because of the antibacterial and antiviral properties [39]. The nanocomposites of Ag (0)-polymer has been manufactured by the various techniques by introducing the precursors of the salts of silver into the polymer network followed by the method of chemical reduction or by laser ablation furthermore processing to form the silver-embedded fibers or silver-bonded polymer micelles [40]. Depending onto the preparation process of the silver particles, the Ag (0)-polymer nanocomposites synthesis can be one stage or two stages. In the one-step process, the silver precursor and the polymer that functions as the stabilizer for the solver nanoparticles segment the same solvent. The selective solvents must be used in this method so the precursor and the polymer can be melted. Additionally, the ethanol and methanol are usually used as a solvent and these solvents should reduce the silver precursors into the nanoparticles of silver. After the homogeneous solution scheme is attained, the solution is then further subjected toward the electro-spinning for the production of silver nanoparticle-containing the nano-fibers [41]. Whereas, in two-step process the conversion of silver precursors into the silver nanoparticles involves an extra step instead of reduction in presence of solvent. Usually silver nitrate is introduced into the polymer solution. After achieving the homogeneous dispersion, the solution is subjected to chemical reduction or laser ablation. The plasma treatment has been described as an operative way to produce the silver nanoparticle in the solution of nylon 6. The chemical reduction has similarly employed to make the silver nanoparticles in the solution of polypyrrole (PPy). At the second stage, electro-spinning is employed to create the silver particles suspended polymer solution into the nano-fiber composites [42].

Though the one-step process is simpler and needs the less treatments as well processing as compared to the two-step process. For the two-step process, since the reduction of silver particle and nano-fiber formation are accomplished into the two separated steps, solvent is not needed in that process that is for reducing the silver precursors and more possibilities of solution structures. Electro-spinning is an adaptable and solid procedure to deliver smaller scale or nano-fibers. Electro-spinning is a fiber framing process, where a high voltage is utilized to make an electrically charged jet of polymer arrangement or soften from the needle. At the point when the voltage is sufficiently high, the electrostatic powers beat the surface pressure of the polymer, and the stream is extended and goes toward the collecting plate. The polymer solidifies among the movement toward the collecting plate, frequently providing the nanometer scale filaments [43]. Nano-fiber development by electro-spinning is influenced by the spinning parameters including arrangement properties as well the concentration, hydrostatic pressure of the capillary tube, the electric potential at the capillary tip, the tip-to-collector distance and the conditions of chamber [44]. By the electro-spinning, the nano-fibers embedded with the silver nanoparticles can be organized, and the morphology can be controlled by the parameters of electro-spinning process. With benefits of the antibacterial and fungicidal properties of silver nanoparticles and high surface-to-volume proportion of nano-fibers, the utilization of the silver-containing nano-fibers extends from biomedical applications to optical materials [45].

The synthesis of the composite film was accomplished by the addition of 100 μl of the different concentrations of silver nitrate ($AgNO_3$) [46] to the solution of chitosan in the presence of 1% acetic acid. The temperature of this reaction plays a significant role as it strongly influences the particle size and silver nanoparticles dispersion into the solution of chitosan [47]. These films were produced by the solvent cast method pouring the finishing solution into the plastic petri dish and allowing the solvent to vaporize. The confirmation of the silver nanoparticles in the metallic state carried out by the XRD and XPS measurements [48].

Silver wires can be directly organized from the aqueous silver nitrate by depositing the reduced silver nanoparticles (AgNPs) onto the self-assembled, 1-D wires of tetra-anilines (TeAN-ES) that are doped with nitric acid which also act as a reducing agent [49]. Nano-silver is utilized for the coating materials, for example, fused in wound dressings, diabetic socks, frameworks, sanitization materials in healing centers, therapeutic materials and so forth.

Nano-silver can be used to cover the wound pads for bandages with assorted sizes for treatment of cuts, burns and scratches. Any antibacterial spray or ointment, (for example, Neosporin) should not be used as it might hinder the silver's fixing properties. Despite the fact that researchers and wellbeing experts have cautioned about the ascent of "supergerms," organisms that have turned out to be impervious to anti-infection medications, microbes appear not able develop a protection from silver. The bandage pad is basically absorbed colloidal silver and is permitted to dry. The nanoparticles of silver impregnate the gauze material and will give against microbial protection when the wrap is connected to an injury. Silver restricts the microorganisms in no less than three courses: by connecting with the cell film, authoritative to the DNA of cells and hindering the digestion of the microscopic organisms. It lessens the development of several distinct sorts of microbes, including some that do not regularly respond to pharmaceutical antibacterial specialists. Since silver obstructs the development and spread of germs through various instruments, it is hard for microbes to develop protection. Dissimilar to some different metals, silver is not toxic to the body—just too wounding organisms. It is additionally not addictive, and is exceptionally hard to overdose on. Notwithstanding many years of handy utilize, late logical examinations on people and creatures have demonstrated that injuries treated with silver heal at a speedier rate than those treated without silver [50] The antibacterial properties were brought into the bandages by drop-cast technique, utilizing 2 and 5% concentrations by weight of silver nanoparticles in water. To decide the measure of the silver nanoparticles and their dispersion over the wraps, Scanning Electron Microscopy was utilized. In the SEM can be watched that more nanoparticles were saved in the bandages with the less concentrated dispersions (2%) [51]. For a specific example for bandage preparations and in order to determine the antibacterial properties, *Escherichia coli* (*E. Coli*) bacteria were used. The bacteria cells were grown into the liquid at 37°C and 250 rpm overnight. After that, the piece of bandages with 0% (blank sample), 2% and 5 % silver nanoparticles were placed into the solution containing E.Coli bacteria and left another 24 h at 37°C.

Silver nanoparticles (AgNPs) are utilized as a part of antimicrobial applications, containing an extensive collection of the consumer goods and apparel. This advanced fiber protection, based upon the nanotechnology also provides the oil and water resistant properties to the textiles. In general, an invisible film is produced onto the surface around the fibers by the product. Resultantly, the dry dirt cannot adhere to the material and the liquid cannot be soaked up by the fibers. Water, coffee and fatty substances are repelled from the treated textiles. Even extreme soiling can be removed certainly without any trace [25].

It is ideal for the clothes made up of wool, silk, synthetics and leather. It can be applied on every textile from finest silk to hard wearing cotton on different garments such as uniforms, hiking clothes costumes, sports jackets, suits, jackets, blouses, shirts, track suits, ties, rain coats, trousers, jeans, anoraks, ski clothing, motorcycle clothing, adventure wear and snowboard clothing [52].

The main advantages of the silver nano coatings

- Environmentally friendly
- Harmless to skin
- Easy handling
- Breathability remains
- Dry cleaning resistant
- Ironing resistant
- Suitable for all textiles
- Long lasting sealing of textiles
- Prevents tea, coffee and ketchup stains etc.

- Simply wash off contaminants
- Washing stable up to 40°C
- The look, texture and breathability of the material remains
- Long lasting protection for the textiles against dirt water and grease

5. Characterization of silver nanoparticles

The synthesized nanoparticles of silver can be characterized by various electron microscopic and absorption spectroscopic techniques [53]. The major among them are atomic force microscopy (AFM), scanning electron microscopy, dynamic light scattering (DLS), transmission electron microscopy (TEM), X-ray photoelectron spectroscopy, X-ray diffraction analysis, UV-visible spectroscopy and Fourier transformation infrared spectroscopy (FTIR). The UV-visible spectroscopy is the most convenient and feasible method for detection of nanosilver as the typical peak of 385–450 nm range predicts the presence of nanoparticles. The powder form of silver nanoparticles is used for capturing SEM image and X-ray diffraction pattern is used to obtain the structural image of the prepared nanoparticles and to determine the size of the nanoparticles [54]. Atomic force microscopy is used for observing the surface morphology and the size of consequential silver nanoparticles [55]. The sample is dropped onto the new cleaved mica pieces and dried overnight. This study of nanoparticles of silver that are deposited onto the mica pieces is executed in a microscope VEECO or Multimode Nano-scope IIIa [56]. At times, after synthesis, the nanoparticles are also examined under scanning electron microscopy (SEM) VEGA3 TESCAN, which provides the clear image of the nanoparticles synthesized [57] and morphological structures of nanoparticles are exposed. Scanning electron microscopy depiction not just provides the structural depiction but also provides the nanoparticles' size in the specimen to recognize whether the nanoparticles are in range of the nano-scale or above [53] (**Figure 2**).

Dynamic light scattering (also known as Photon Correlation Spectroscopy) is an important technique, mostly used in recognizing the distribution pattern of the size of very small particles present in the suspension or in the solution. This light scattering (Malvern) technique is being used to recognize the size distribution pattern of the silver nanoparticles synthesized biologically or other methods [58]. Transmission electron microscopy (TEM) demonstrates the crystal structure, shape as well as the size of the nano- particles [59]. The grid for this analysis is arranged by placing a drop of the nanoparticle suspension on a carbon-coated copper grid and allowing the water to evaporate inside a vacuum dryer. The grid covering with the silver nanoparticles is scanned by the Transmission Electron Microscope [60]. Similarly, the X-ray beam photoelectron spectroscopy (XPS) estimations have been done to clear up the surface compound conditions of the nanoparticles. Silver nanoparticles are explored by XPS to describe the idea of the surfactant chemisorbed to the surface. It is utilized to inspect the valence of the subsequent silver nanoparticles while it also gives the additional information with respect to the structure of the silver nanoparticles encapsulated into the organic linkages [61].

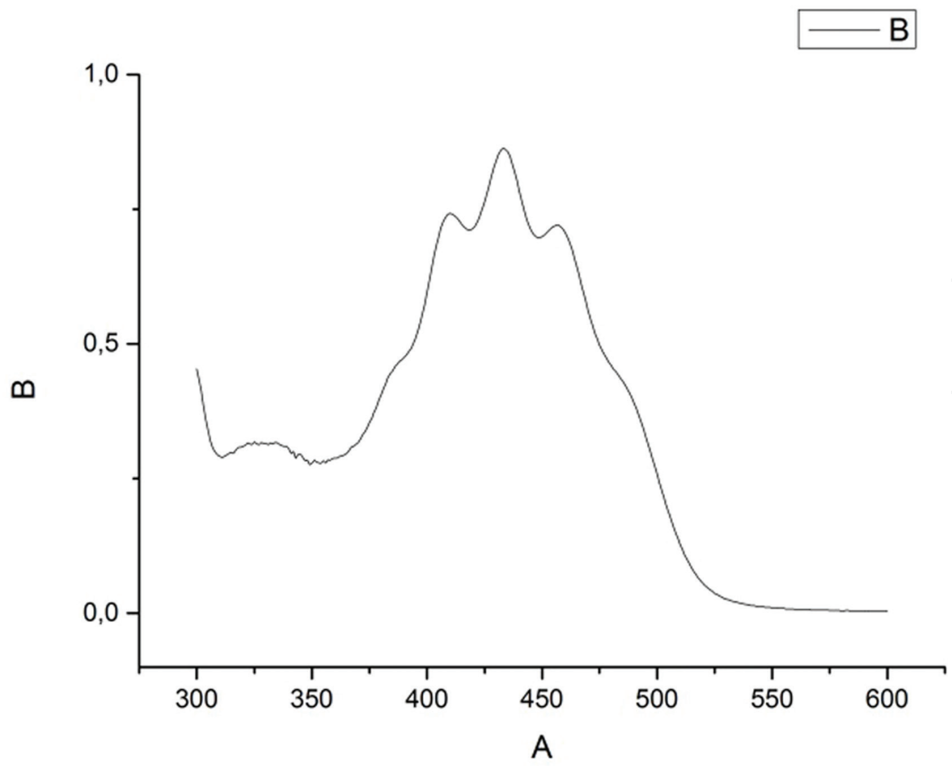

Figure 2. The exemplary UV-visible spectra of silver nanoparticles prepared from orange juice.

In contrast the crystal structure and respective particle size is calculated via X-ray diffraction analysis [62]. The diffracted intensities are recorded from 35.01 to 79.99° at 2θ angles. The crystalline size is calculated from the half-height width of the diffraction peak of XRD pattern by using the Debye-Scherrer equation [63].

$$D = \frac{K\lambda}{\beta cos\theta} \tag{1}$$

where D is the crystalline size, $\acute{\AA}$, K is the crystalline-shape factor, λ is the X-beam wavelength, θ is the watched crest point, degree [64], β is the X-beam diffraction expanding, radian.

The change of the color into the reaction combination of the metal ion solution during nanoparticle formation is generally recorded by the visual observation. The synthesized nanoparticles of silver are confirmed by sampling the aqueous component of two hour after the reaction and the absorption maxima was scanned by the UV-Vis spectrophotometer at the wavelength of 325–825 nm onto the Beckman Du-50 Spectrophotometer [65]. The absorption as well into the visible range directly reflects the perceived the color of the chemical convoluted in the whole synthesis process [56]. For the measurements of FTIR, the synthesized silver nanoparticles arrangement is centrifuged at 10000 rpm for 30 min. The pellet is washed thrice with 5 ml of deionized water to dispose of the free proteins or chemicals that are not topping the silver nanoparticles. The pellet is then dried by utilizing vacuum drier to measure the recording through FTIR [66] (**Figure 3**).

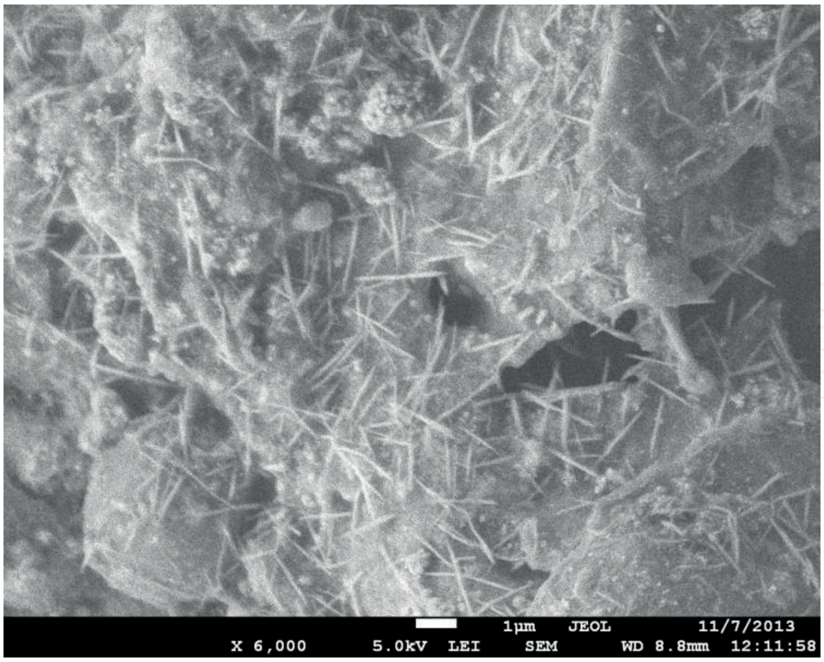

Figure 3. The SEM images of silver nanoparticles from Sumbla plant.

6. Antibacterial properties

Both, the Gram-positive and Gram-negative microorganisms are successfully killed by nano-silver, so it can call as executing agent including the anti-toxin safe strains [67]. Gram-negative microscopic organisms are the microbes which hold the shade of the stain even in the wake of washing with liquor acetone or alcohol as well include genera, for example, Salmonella Acinetobacter, Escherichia, Vibrio and Pseudomonas [68]. The Acinetobacter species are related with nosocomial diseases, i.e., contaminations that are the consequence of treatment in a doctor's facility or a human services benefit unit, however auxiliary to the patient's unique condition. Gram-positive microscopic organisms are those which lose the shade of the stain after wash with liquor or acetone and incorporate some outstanding genera, for example, Staphylococcus, Listeria, Bacillus, Enterococcus, Streptococcus and Clostridium [69]. Anti-toxin safe microbes are the microscopic organisms that are not controlled or murdered by anti-toxins which incorporate strains, for example, *Staphylococcus aureus*, and Enterococcus faecium, methicillin-safe and vancomycin-safe [70]. To improve the antibacterial action of different antibiotics, penicillin G, amoxicillin, erythromycin, clindamycin and vancomycin against *Staphylococcus aureus* and *Escherichia coli*, the silver nanoparticles assumes to be an extremely evident part. The antimicrobial movement of silver nanoparticles relies upon their size and Gram-positive microorganisms [71]. The little-sized nanoparticles with a vast surface range to volume proportion give a more effective intends to antibacterial action even at low fixation. Additionally, the antimicrobial action of silver nanoparticles relies on the fixation and shape [72]. The diverse shapes silver nanoparticles of circular, pole formed, truncated triangular nano-plates have been created by manufactured progressions [73]. Because of their

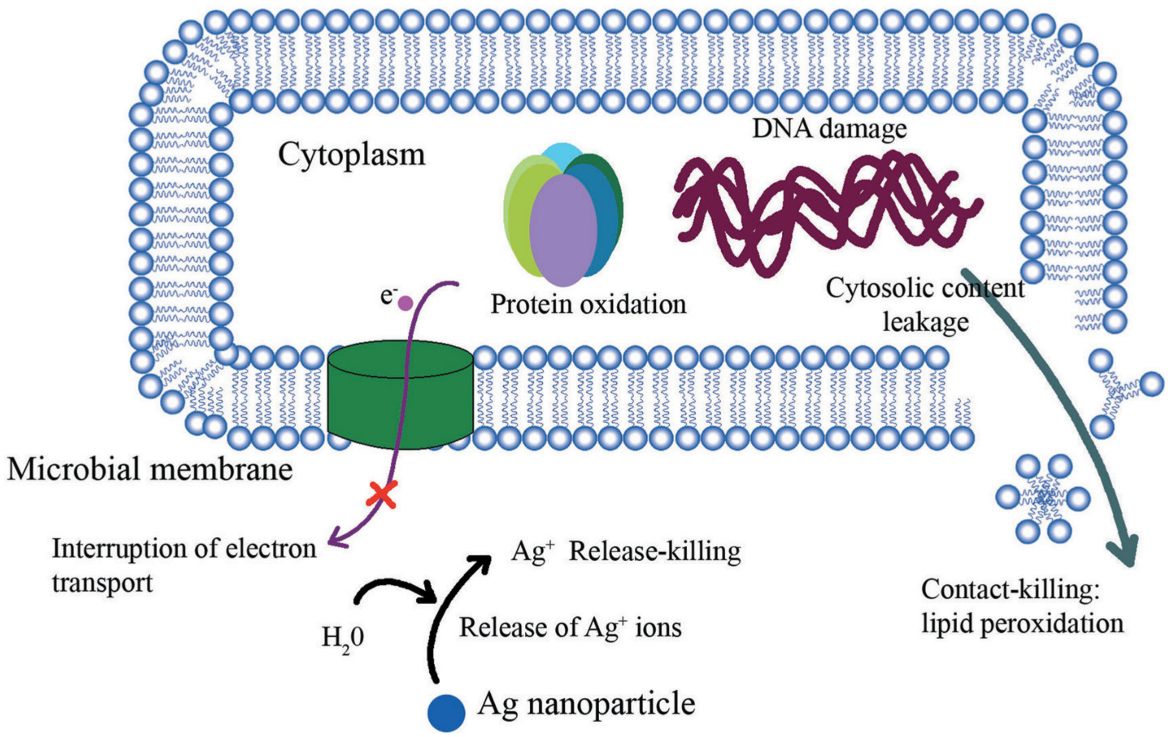

Figure 4. Silver nanoparticles rupturing the cell membrane.

expansive surface zone to volume proportions, truncated triangular silver nano-plates show the most grounded antibacterial action [74] (**Figure 4**).

6.1. Factors affecting the antimicrobial activity of silver nanoparticles

Silver nanoparticles are right now utilized as a part of the type of colloids, comprising mostly of diffused nano-metric silver particles, a stabilizing element and also act as a solvent [75]. Biological action of silver nanoparticles relies upon the morphology and physicochemical properties of the nanoparticles, and in addition the particular qualities of microorganisms which are dealt with by silver nanoparticles [76]. One can recognize various elements influencing the antimicrobial action, for example, shape, size and zeta (ζ) potential of the metal particles which impact the surface properties of the particles and the stabilizer, the pH of the suspension, ionic quality contaminants and so forth [77].

6.2. Mechanism of antibacterial activity of silver nanoparticles

Usually it is broadly recognized that the main antibacterial effect of silver nanoparticles or silver nanoparticles-based materials is due to the partial oxidation of nanoparticles and due to the release of the silver ions (Ag+) [78]. Later on the oxidation takes place, resulting the following actions that can happen either separately or simultaneously;

1. The uptake of the free silver ions (Ag+) followed by the interference of ATP production and DNA replication

2. Silver nanoparticles and silver ions (Ag+) interaction takes place with the bacterial proteins, by disrupting the synthesis of protein

3. Silver nanoparticles directly damage the cell membranes, interacting with the peptidoglycan wall cell and the plasmatic membrane causing cell-lysis [79].

7. Conclusion

In sum, the exploration of silver nanoparticle and related materials is established in this chapter. The availability, comparatively inexpensive price, ease of formation of nanoparticles and related materials and less toxic nature of silver as compared to other transition metals make silver and its nanoparticles special place in material science applications. The nanoparticles either prepared through natural extract or via synthetic routes from commercially available chemicals in laboratory both are of equal benefits when utilized in the development of functional materials. The polymers, emulsions, resins, natural extracts, carbohydrates, materials for water cleaning application, electronics, textiles and all related applications specially human health and environment make silver nanoparticles an essential addition.

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