Chapter

Silver Nanoparticles in Various New Applications

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Abstract

The use of silver in antimicrobial management is very ancient. Silver-based materials have proven interesting, practical, and promising for various applications. Silver nanoparticles (AgNPs) have been one of the nanostructures most studied and investigated over the past several years. AgNPs have greater specific properties depending on their size and form. These noble synthesised metrics have numerous optical, electrical, catalytic, and optical characteristics. These properties are ideal for many fields, depending on their size and shape. The outbreak of multiple infectious diseases has been a major strain on global economies and the public health sector. Extensive treatments have been suggested for disease control in environments containing infectious diseases through advanced disinfectant nanomaterials. This chapter investigates the application and mechanism of silver nanoparticles in certain nanobiotechnology sectors as a useful nanomaterial. In the sense of the market statistical survey research, AgNPs are emerging as one of the fastest developing product groups in the nanotechnology industry, providing a wide variety of nanosilver products in various applications. Lastly, due to the massive use of AgNPs in products recently, there are many concerns about AgNPs toxicity and safety had also been discussed.

Keywords: nanotechnology, metal-nanoparticles, silver nanoparticles, nanomaterials and applications

1. Introduction

The phrase 'nanotechnology' was proposed in 1974 by Norio Taniguchi, a researcher at the University of Tokyo, who pointed to the possibilities of treating nanometric materials with dimensions between 1 and 100 nm. In this variety of sizes, particles show new physical and chemical properties that can be used in various fields of science, such as medicine, food, textiles, chemicals, and energy, to name a few. Nanotechnology is a dynamic interdisciplinary science consisting of nanochemistry, nanophysics, nanomaterials science, nanoelectronics, optoelectronics and nanoengineering, nanobionics and nanometrology, nanodevice-building and nano-craft [1].

Metal nanoparticles are currently starting to be used as silver (Ag), gold (Au), and copper (Cu) with biochemical, optical, and magnetic properties, of which AgNPs are the most studied because of their antimicrobial ability for microbes, viruses, and fungi [2]. AgNPs have been used in nanomedicine and also being known as antimicrobial agents and disinfectants without adverse effects. AgNPs have been used against both aerobic and anaerobic microbes. As correlated with other compounds, great interest in AgNPs increased because it shows more efficacy [3]. Its antimicrobial properties can be linked to many internal systems such as communicating with the S–S disulfide bond of the metabolic enzymes, cleaving cells, and disrupting the respiratory chain [4].

Antimicrobial resistance is a public health problem increasing day by day as it is caused by microorganisms that gradually became resistant to drug therapy. Population overcrowding, urbanisation, inadequate water supply, and lack of environmental hygiene are also the major factors of rapid disease outbreaks. Many scientists had developed new effective antimicrobial reagents against the increasing number of microbial resistances with various antibiotics, due to clinical limits on antibiotic prescription. The use of smaller-size AgNPs with a larger surface area to volume ratio as they can enter cell cytoplasm rapidly and kill microorganisms effectively was proven compared to larger AgNPs. At very low concentrations of 5 mg/ml only, AgNPs act as effective antimicrobial activity against both gram-positive and negative bacteria. Furthermore, it has been revealed that AgNPs solution showed an anti-fouling effect on certain bacteria strains [5].

Fungal infections are also very common in immunosuppressed patients. Overcoming fungal diseases is a boring process due to the small number of antifungal drugs available in the current scenario. There is a solution to the urgent and inevitable development of antifungal agents that would be non-toxic, biocompatible, and eco-friendly. At this part, AgNPs play an important role as antifungal agents against various fungal diseases. AgNPs were tested towards different phytopathogens like *Fusarium solani*, Curvularia lunata, and showed efficient antifungal activity [6].

Nowadays, the AgNPs synthesis process is cost-effective, economical, energy-efficient, and offers healthy workplaces to societies. Hence, health and environmental safety surely leading to less waste and safer goods. The utilisation of the plant method can be useful in comparison to other biological processes. The plant-based method can shorten the time-consuming processes compared to microbes and retain their capacity during AgNPs synthesis.

1.1 New emerging applications of AgNPs

The most promising nanomaterials for current commercial applications are AgNPs. They function as antibacterial agents and are used in textiles, electronics products, the medical industry, environmental applications, coatings, food preservation, and other applications. AgNPs are widely used for different uses from home appliances and are used as a disinfectant for sewage treatment and surgical equipment for sterilisation [7]. The most promising nanomaterials for current commercial applications are AgNPs are used as a coating for cardiovascular implants and central venous and neurosurgical catheters, in latex membranes where AGNPs are applied as a biomaterial for a skin regeneration treatment and monitor the delivery rate of the nanoparticle membranes [8].

AgNPs are used in biosensors, where the silver nanoparticles content is used for quantitative detection as biological tags. AgNPs are also incorporated in clothes, shoes, paints, wound dressings, appliances, cosmetics, and plastics. AgNPs are used to improve conductivity in conductive tinting and are incorporated into composite systems. AgNPs are used in opical applications for the effective collection and enhanced optical spectroscopy, including improved metal fluorescence (MEF) and superficial Raman dispersion (SERS). With regard to nanoelectronics, optoelectronics and nanoengineering, innovative technological processes, nanomotors, nanoactuators, nanodevices, micro-opto-electro-mechanical systems (MEMS, MOEMS), ultra-large integrated circuits (ULCI), nano-robots, etc. were the new applications. **Figure 1** is the various applications of AgNPs meanwhile **Figure 2** are the listed advantages and disadvantages of AgNPs utilisation.

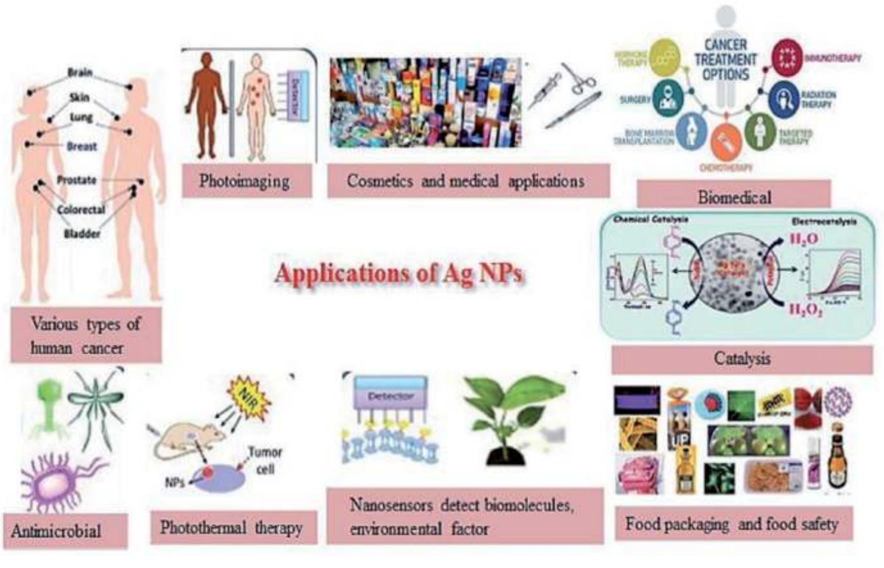

Figure 1.
Various applications of silver nanoparticles.

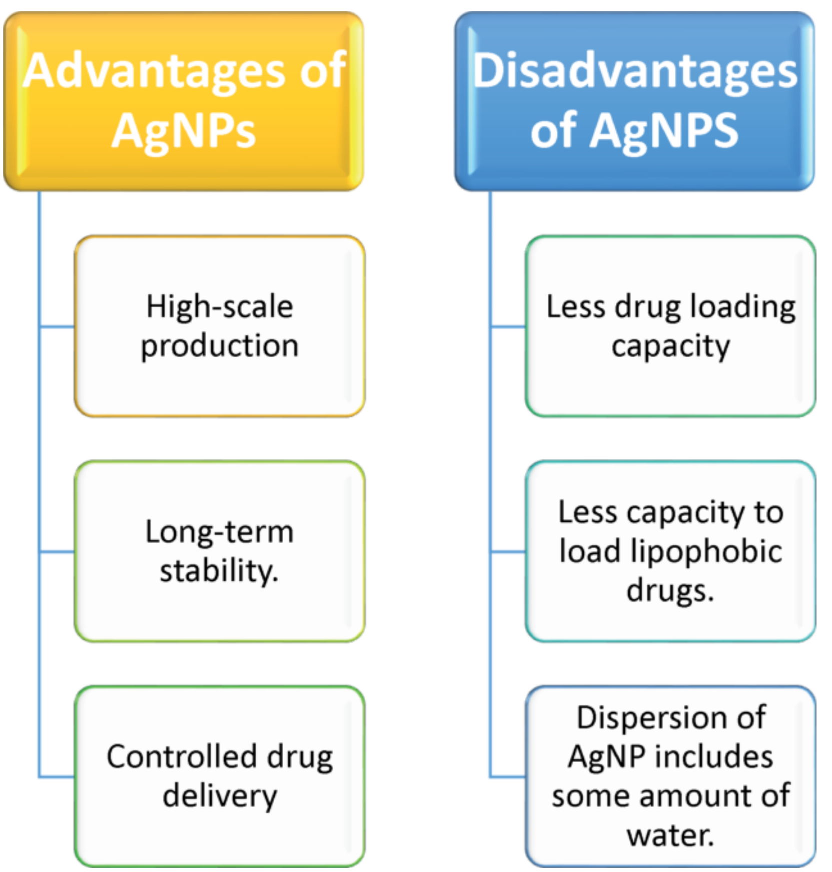

Figure 2.
The advantages and disadvantages of AgNPs utilisation.

2. Nanobiotechnology related applications

Many research techniques are introduced in various physical and chemical methods by scientists to develop metal nanoparticles. However, these approaches for various synthetic compounds are costly. They may result in the presence on the surface of nanoparticles of toxic chemical organisms, which have potentially harmful impacts in diverse biological and biomedical uses [9]. The need to develop environmentally sustainable methods for synthesising nanoparticles by "green synthesis" is increasing.

AgNPs are among the most thoroughly studied nanomaterials and the most common target of the above listed 'green' methods, which fascinate scientists. The research fields of research and the development of nanoparticles with plant extract are emerging. Intracellularly and extracellularly, the plant structures can be used to manufacture various metal nanoparticles [10]. Intracellular processes in nanoparticles' processing include seed plants in high-metal media and hydroponic solutions, such as metal-rich soils. While extract leaves, prepared by boiling or moulding leaves in water or ethanol, are an extracellular processing nanoparticles method [11]. *Medicago sativa* is a plant that can synthesise silver and gold nanoparticles by exploiting its biomolecule which is the first plant recorded used for the extracellular synthesis of a nanoparticle [12]. Since then, plants have gained considerable attention as a medium for the synthesis of nanoparticles. AgNPs have been identified for use in the treatment of wounds, burns, in the development of nano-containing materials for bone implants, dental materials, and antibacterial, antifungal, antiviral, anti-protozoans, anti-arthropods, anti-larvicidal anti-cancerous agents. $AgNO_3$ was used clinically as an important antibacterial agent until the invention of AgNPs [13]. The use of nanostructured materials in nanotechnology has been growing quite rapidly in the last few years. It is used for promising biomedical applications to detect and prevent different forms of diseases. AgNPs can be easily coated with titanium or titanium alloys and are used for dental titanium implants [14].

2.1 Wound healing

Wound healing is a complex biochemical pathway, including several cells that work to regenerate functional skin, including skin cells and immune cells. The use of silver in wound management is very ancient. Pharmaceutical companies and scientists are searching for new antibacterial due to infectious disease attacks and the development of antibiotic resistance. Silver-based products with more complex shapes and increased effectiveness than conventional dressings have been patented and commercialised in wound dressing applications. In wound care, biopolymers combined with a bioactive antimicrobial, antibacterial and anti-inflammatory nanoparticles have great potential to promote wound healing, particularly in the management of diabetic foot ulcers (DFUs), which still pose a huge problem and are associated with high amputation rates and clinical costs [15].

Silver plays an important function in wound healing and, along with its distinctive role in avoiding infection, AgNPs may also facilitate the transformation of fibroblasts into myofibroblasts, which in turn facilitates wound contracting, accelerates the pace of healing, and induces keratinocyte proliferation and relocation [16]. As reported by [17], the effect of nanosilver was tested in vitro and in vivo, and the result showed that, at a concentration of 10 ppm, AgNPs facilitated fibroblast migration, which also demonstrated higher levels of the alpha-smooth muscle actin (alpha-SMA) marker, signalling silver's capacity to turn fibroblasts into myofibroblasts and speed up the healing phase. Several laboratory animal models, such as rat (*Rattus norvegicus*), rabbit (*Oryctolagus cuniculus*), and pig (*Sus scrofa*), are used to test AgNP antibacterial effectiveness in wound healing [18, 19]. Studies in the Sprague–Dawley rat and pathogen-free domestic pigs found that AgNP-loaded dressing speeds up excisional wound healing, while after treatment, the wounds suffer from bacterial infection [18]. Pig explant culture model and mouse experiments have reported that AgNP dressing prevents epidermal cells' proliferation and re-epithelialisation of wounds [20]. The caudal fin of Zebrafish, including the epidermis, blood vessels, nerves, pigment cells, and fibroblast-like cells, has a relatively basic but symmetric structure [21]. The major wound healing mechanisms in mammals include the regenerative adult zebrafish fins [22]. Furthermore, the fin regeneration of adult zebrafish is an ideal model for studying the effects of chemicals on tissue regeneration and wound healing.

2.2 Antimicrobial applications

The interest and understanding of the antibacterial potency of AgNPs have been highlighted with the advancement of nanotechnology. A comparative study of AgNPs, $AgNO_3$, and AgCl find that the antibacterial efficacy of AgNPs is greater than that of free silver ions [23]. The AgNPs have known to be an active bactericide against several bacteria, both Gram-negatives and Gram-positives, including several highly pathogenic bacterial strains [13]. As reported by [24], an experiment was carried out using a model of both Gram-positive (*Staphylococcus aureus*) and Gram-negative (*Escherichia coli*) bacteria to explore the antibacterial properties of AgNPs. *E. coli* development is inhibited at a very low concentration of AgNPs (3.3 nM), which is ten times lower than the minimum inhibitory concentration (MIC) of *S. aureus* (33 nM). The robust antibacterial efficacy and improved stability of AgNPs (10–15 nm) against various drug-resistant bacterial strains were recorded in another study. There are several records that the dose-dependent antibacterial activity of AgNPs is more prevalent against Gram-negative than Gram-positive bacteria [25]. Furthermore, the AgNPs also found potential antibacterial activity against multidrug-resistant gram-negative such as *Klebsiella pneumonia* and *E. coli* and for gram-positive bacteria *like S. aureus*, which isolated from human pathogens. Different parameters impact antibacterial behaviour AgNPs including size and shape, time of exposure [26]. Silver concentration, compound forms, and microorganisms of the targets [27].

Silver reagent ($AgNO_3$, AgCl) has to be high enough to inhibit bacterial cell growth. In the case of aquaculture, one of the greatest problems was preventing diseases caused by viruses, microbes, fungi, and parasites. Traditionally, antimicrobials have been used to eliminate bacterial infections in aquaculture. However, excessive application of these chemicals has caused resistant strains, rendering the treatments not so effective. A previous study by [28] analysed resistant strains in fish farmers in 25 countries showed that tetracycline was the antibiotic most widely used. The isolated tilapia bacteria show a wide variety of antibiotic resistance, such as tetracycline, erythromycin, and streptomycin. Resistant strains were *Aeromonas salmonicida, Photobacterium damselae, Yersinia ruckeri, Listeria sp, Vibrio sp, Pseudomonas s*p, and *Edwardsiella sp.* AgNPs were synthesised to control Vibrio harveyi by *Camellia sinensis* in infected *Feneropenaeus indicus* organisms. In vivo tests have shown that the concentration of 10 μg mL-1 inhibited 70 percent bacterial growth [29]. *Bacillus subtilis*, a non-pathogenic organism used to synthesise nano compounds, was evaluated for its antimicrobial effect on *V. parahaemolyticus* and *V. harveyi* in infected *Litopenaeus vannamei*. The results showed a survival rate of 1% in the control group, but a survival rate of 90% with nano compounds [30]. AgNPs encapsulated with starch and applied in immersion baths (20 minutes) at 10 ng of nanoparticles' concentrations, infected by *Ichthyophthirius multifiliis* and *Aphanomyces* parasites, anti-parasitic and antifungal impact. The findings revealed that the fish recovered after three days without any toxic impact on the use of AgNPs [31]. Much research has been done to prove the effectiveness of silver nanoparticles as disease control in aquaculture (**Table 1**).

2.3 Antifungal applications

The efficacy of AgNPs compared to free silver against a wide range is mostly found in fungi like *Aspergillus, Candid*a, and *Saccharomyces,* and it is as fungicide properties also reported by [32]. Antifungal action of AgNPs in conjunction with heterocyclic compounds like Pyrazolo, thiazolidine, tetrazole, phthalazine, and pyridazine derivatives have been tested against *Aspergillus falvu*s and *C. albicans.* Results have reported enhanced antifungal efficacy of AgNPs combined with heterocyclic compounds in contrast to heterocyclic compounds alone. AgNP antifungal properties against commonly found fungal strains and recorded MIC of AgNPs vs. *Candida albicans, Candida glabrata* varied from 0.4 to 3.3 μg/ml. Additionally, emerging viral diseases are the main threat to human and veterinary sector. **However, AgNPs have established tremendous attention for their antimicrobial properties, but the antiviral properties for AgNPs remain an unexplored**

AgNPs characteristics	Microorganisms	Results
AgNPs with chitosan	*Aliviibrio salmonicida*	MIC, 50 μg mL^{-1} and 2-(3-cyano-phenyl)-1H-Benzimidazole (MCB), 100 μg mL^{-1}
Commercial nanoparticles of Al_2O_3, Fe_3O_4, CeO_2, ZrO_2, MgO,	*Aeromonas hydrophila, Bacillus subtilis,Vibrio harveyi,Vibrio parahaemolyticus and Serratia sp.*	The CeO_2 Naps show higher antibacterialthe effect when 10 μg mL-1 concentration wasused.
Nanocid®	*Streptococcus iniae, Lactococcus garvieae, Yersinia ruckeri, Aeromonas hydrophila*	*S. iniae* MBC of 5 to 0.15 μg mL^{-1}, *L.garvieace* MBC of 10 μg mL^{-1} to 0.62 μg mL^{-1}, *A. hydrophila* MBC of 0.31 μg mL^{-1} to <0.15 μg mL^{-1}, *Y. ruckeri* MBCs of 2.5 to 0.62 μg mL^{-1}
Nanoparticles of CuO, ZnO,Ag, TiO_2	*Aeromonas hydrophila, Edwardsiella tarda, Pseudomonas aeruginosa, Flavobacterium branchiophilum, Vibrio spp Staphylococcus aureus, Bacillus cereus and Citrobacter spp.*	Show antibacterial effect in tested strains.
Synthesised nanoparticles with leaves of *Mangifera indica*, *Eucalytus terticonis, Carica papaya* and *Musa paradisiaca* plants	*Aeromonas hydrophila*	Synthesised nanoparticles with *Carica papaya* show antimicrobial activity with 153.6 μg mL^{-1} concentration.
Synthesised AgNPs with *Boerhaavia diffusa*	*A. hydrophila, P. fluorescens and F.branchiophilum.*	AgNPs concentration (50 μg mL^{-1}) was demonstrated higher zones of inhibition (15 mm) for *F. ranchiophylum*, 14 mm for *A. hydrophilla* and (12 mm) for *P. fluorescen.*

Table 1.
The application of silver nanoparticles used as pathogen control in aquaculture.

area. Therefore, a new, unique and develop technique needed to overcome the problem of antiviral resistance. As a result of their possible antiviral efficacy, AgNPs are emerging as a better approach to treating viral infections in HIV-1 and influenza at a certain stage.

3. Food and personal care industry

AgNPs in the food industry, [33] reported for antibacterial and conservation-free action, are commonly used. Most viruses and bacteria are harmless for humans but lethal, so they are used for sanitising food and drink every day, and they are immune to drug infections. Nanosilver fresh food bag is one of the bags that are ready for sale on the market. Because of its anti-fungicidal and anti-bactericidal activity, AgNPs are commonly used in everyday goods such as soap, fruit, plastics and pastes. Nano-based smart and active foods provide many advantages over standard packaging approaches to increase mechanical efficiency, barrier properties and antimicrobial films for nano-sensitive pathogens identification and alert customers to food protection [34]. "Active content" nanocomposites for packaging and material food packaging may also be strengthened with coating. Many researchers are aware of and important to organic compounds' antimicrobial characteristics, such as essential oils, organic acids and bacteriocins as an antimicrobial packaging, polymeric matrices. However, these compounds cannot be used for different processing phases in food susceptible to physical environments that require high temperature and pressure. Inorganic nanoparticles' use makes it possible to obtain good antibacterial activity in low concentrations and become more soluble under intense conditions. It is also noteworthy that these nanoparticles are recently used in antimicrobial food packaging [35]. Control of food quality has become a global, very common problem. AgNPs have unique physicochemical properties that can be used to produce, package and store food. AgNPs could additionally develop into detectors that are capable of recognising or responding to changes in environmental conditions, such as molecular contaminants, microbial quality organisms, gases. Another popular method used is electrochemical detection based on nanomaterial sensors in the food sector [36].

AgNPs had been added into skincare (**Figure 3**), body wash, cosmetics, deodorants, and others with the advancement of personal care technology. This had urbanised the use as antibacterial agents of AgNPs. AgNPs are added as an antiseptic into personal care products for skin problems. Interestingly, AgNPs also have been incorporated in make-up remover cloth, textiles, gloves, bath towels and cleaning fabrics. Such an application's relevance is silver's natural ability to remove

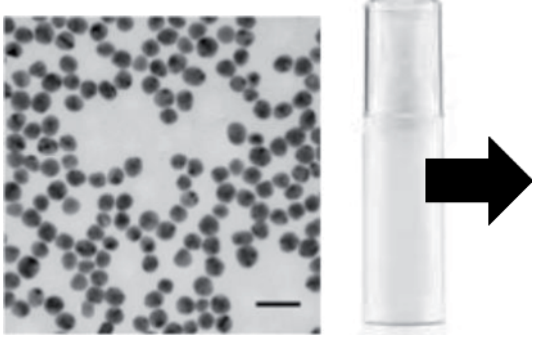

Figure 3.
AgNPs image with 20 nm diameter under a transmission electron microscope (TEM) in a skincare product.

bacteria as a major cause amount of infections in the skin. Silver ions also prevent their persistence and eliminate them very easily on the microfiber fabric. AgNPs are very helpful in maintaining the optimal balance of the skin condition as they preserve a stable pH by preventing usage of other chemicals in a wide range of items. Regardless of gender or age, AgNPs have shown excellent results, including people with the most sensitive skin. It was tested that consumer goods that contain small quantities of AgNPs do not have major effects on health.

4. Nanophysics applications

Nanophysics is an area which studies more the artificial assembly and fabrication of nanostructures as well as research of their external size effects. To identify and measure them, Nanophysics develops different devices and instruments. A range of manufacturing techniques, including e-beam lithography, focused-ion-beam milling, nano-manipulation, and self-assembly, are used to create novel materials, structures and devices [37] Novel nanostructured architectures have been developed in nanomaterial science. In addition, functional nanomaterials and intelligent nanocomponents with special properties have also been manufactured with the integration of AgNPs [38].

4.1 Fabrication of antennas

There are two ways of silver-based antenna fabrication. The first fabrication is with nano-metallic silver, and the other one contains micrometre-sized grains. These two samples are prepared through a thick-film fabrication procedure. The metal powder is used as a material for preparation; the metal oxide is used as an inorganic metal binder and an organic vehicle that evaporates through the initial stages. These samples are usually characterised for electrical performances. It was found that in the lower frequency range, of both samples had similar behaviour with a loss in an electrical parameter and linear increase in the frequency range (from 0.1 dB/mm/GHz up to 80 GHz), but beyond 80 GHz frequency, the prepared AgNPs had a lower electrical loss, for the entire frequency range. The lower loss from the AgNPs and the broad range in loss per wavelength does not rely on the frequency. Hence, it has been summarised that the AgNPs fabricated conductors showed a very less electrical loss with higher frequency range which in turn assigned to the roughness present in the lower side of the nanoparticles because of better packing may allow opportunities for low-temperature fabrication of antennas and sub-THz metamaterials with the improved performance [39].

4.2 In electronically conductive adhesives

AgNPs can be utilised as a silver paste in the electrodes due to their high conducting nature. It is also used as conductive fillers in electronically conductive adhesives (ECAs). A few of the research groups have prepared the AgNPs by reducing the silver nitrate with ethanol in polyvinylpyrrolidone (PVP) [40]. Different reaction conditions have been tuned like PVP concentration, reaction time, and reaction temperature. In this method, PVP prevents aggregation; and also increases the nucleation rate spontaneously and simultaneously decreases the size of the silver nanoparticles. Ethanol is used as the reducing agent to adjust the viscosity of the ECAs. The produced AgNPs with the chemical reduction method showed very fine dispersion and narrow size distribution. Ethanol is also used for the re-dispersing of AgNPs. The absorption peak was recorded at 410 nm, which is an indicator of the quantum size effect of the AgNPs, which is occurring in the absorption property of AgNPs. It is also summarised that the size of the AgNP has been decreased with an increase in the concentration of silver nitrate, the increase in reaction temperature, and the reaction time.

Researchers have synthesised AgNPs, silver nanorods, and epoxy resins containing high-performance electrically conductive adhesives (ECAs) using a novel preparation method. The synthesised nanoparticles and nanorods were dispersed well, with the absence of agglomeration in the matrix. The volume electrical resistivity tests determine the volume electrical resistivity of the ECA was close correlates 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. Hence, they found that the synthesised and prepared ECA to tend to achieve low-temperature sintering and showed excellent electrical, thermal, and mechanical properties [40]. **Nano metal particles such as Ag, Cu, Zn, and Au are particularly useful for electrical circuitry development because nano-sized metal particles can be shielded from inks and can also be used to boost electrical conductivity. Uniformly formed AgNPs are capable of exhibiting improved electrical conductivity, which makes electronic stuff beneficial. Films with sufficiently smooth and continuous surface morphology may be manufactured by adding AgNPs at a level of 0.05 g/100 g (0.05 per cent) in the CS-GL matrix. It has also demonstrated desirable mechanical strength for industrial packaging. CS-GL-AgNPs at 0.1 g/100 g (0.1 per cent) amount of film proved to be a promising protective packaging material that could increase the shelf life of red grapes by 14 days.**

A study [41] reported a simple method to manufacture surface improved fluorescence spectroscopy (SEFS) substrates based on highly sensitive superhydrophobic Ag nanorods (AgNR) arrays using the glancing angle deposition method at 133 K substrate temperature and resultant coating of molecules of heptadecafluoro-1-decanethiol (HDFT). SEFS substrates display more than 3 times greater fluorescence signal amplification than traditional AgNR films in the HDFT coated superhydrophobic AgNR arrays (In **Figure 4**).

4.3 Ink-jet printing

Ink-jet technology for electronic circuit manufacturing at very low costs has been used, and additional applications in this desirable technology have been noted. It is very interesting to create powerful inks for the versatile display of electronic devices using ink-jet technology. Researchers have prepared the AgNPs through chemical reduction from the silver nitrate using triethylamine to reduce and protect agents. The nanoparticles have been sintered through washing it with

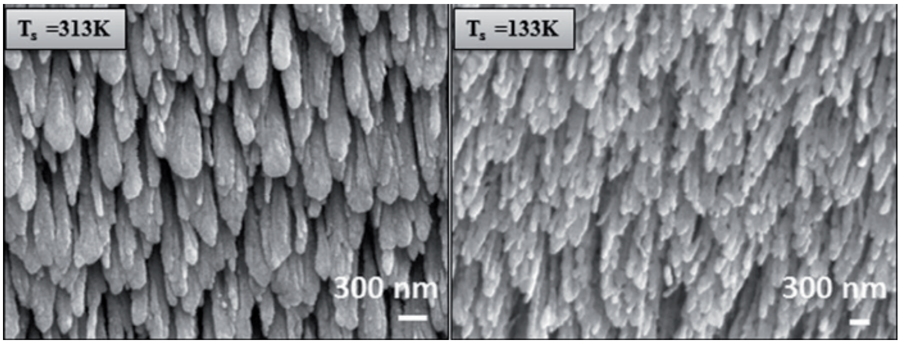

Figure 4.
SEM image of silver nanorods grown on the Si substrate at (a) 313 K and (b) 133 K [41].

acetone and deionised water to remove the particles and organic contaminants present on the surface; after cleaning the film, it was treated with ozone by UVO-100 UV ozone for 30 min. These AgNPs suspensions were spin-coated with 500 rpm, 15 seconds on the polyimide substrate and dried at room temperature to remove the solvent. The resulting AgNPs on the polyimide substrate was heated from 100 to 200 °C and held at 200 °C for 1 h to convert to silver films. The synthesised AgNPs were sintered at different temperatures, and it was shown that the resistivity of the silver film sintered at 150 °C for 1 h was close to the resistivity of bulk silver. Upon the results, the prepared nanoparticles showed a low sintering temperature. Therefore, silver nanoparticles would be used to construct the electronics through ink-jet printing [42].

4.4 Fillers

The micro-sized silver particle fillers are seen as full density silver flakes; they had demonstrated to be highly porous agglomerates. Conjugated polymers with different nanoscale filler inclusions **have been investigated for** sensor applications, including gas sensors, biosensors, and chemical sensors. **Nanofill**ers used include nanowires of metal oxide, nanotubes of **carbon and nanoscale** silver [43]. In the coming decades, nanofiller-based silver nanoparticles and their related products are very promising. In the future, we will face many risks and challenges, in particular energy problems, and research into sustainable energy conversion is expected to explode, both theoretically and experimentally, and polymer nanocomposites will not stand out from this trend, such as self-cleaning or "easy-to-clean" coatings, coated on the surface of a building, protective substrates and glass can help to save energy and water in facility cleaning. In contrast, insulating nanocomposite coatings can help save billions of dollars in energy savings to keep homes in winter.

4.4.1 AgNPs as inorganic filler

Mineral or metallic fillers are reviewed as inorganic fillers. Clay, nano clay [montmorillonite (MMT)], silver nanoparticles (AgNPs), and calcium carbonate ($CaCO_3$) are the most common inorganic reinforcement material-based composites. AgNPs is also a popular metallic filler due to its physicochemical properties, including optical, electrical, catalytic, antimicrobial, and therapeutic properties. It can be synthesised either chemically or biologically. Conventional physical and chemical methods are more costly and toxic than biological methods that can produce nanoparticles in high yields, with good solubility and stability [44]. The biological method is most preferred and very simple, cost-effective, fast, environmentally friendly, and non-toxic. The green approach is preferred for synthesising AgNPs because it uses bacteria, plant extracts, fungi, vitamins, and amino acids far from chemical methods. Few researchers had analysed these nanoparticles via TEM. The resistivity was also evaluated through various levels of filler loading. The AgNPs prepared and synthesised were spheres and nano-sized approximately 50–150 nm in diameter and micro-sized particles with diameters of 5–8 μm, and flakes of silver of 10 μm in length. The data concluded that it was not easy to find the cross-linkage of particles, and there are very lesser chances of different contact and contact area. Through the resistivity measurements, it has been demonstrated that the conductivity of micro-sized silver particle-filled adhesive is influenced by constriction resistance, the AgNPs-containing adhesive is controlled by tunnelling and even thermionic emission. Therefore the particular AgNPs were succeeded to increase the electrical conductivity [45].

4.5 Solar cell optimisation

In recent years, the emerging technology in plasmonic effects in thin-film silicon solar cell is widely studied. It has been a promising application in solar cell fabrication industries due to the nanoscale properties of the silver nanoparticles established in the interface between the metal and dielectric contacts which in turn enhance the light-trapping properties of thin-film silicon solar cells through an increase in absorbance capacity and production of hot electrons that enhance the photocurrents in the solar cell [46]. Silver indium sulphide quantum dots (QD) supported by glutathione (GSH) and polyethylene (PET) as dual-ligands have been synthesised by [47] using an environmentally friendly and reproducible aqueous method. The resulting silver indium sulphide quantum dots present surprisingly long lifespans of 3.69 ls, excellent fluorescent stability and low cytotoxicity, making them the ideal candidate for real-time bioimaging. Thus, they can effectively passivate the surface trap centres and thus reduce non-radiative emissions in **Figure 5**.

4.6 Biosensor fabrication

Few groups have tried to fabricate nano-enzymatic glucose biosensors by depositing AgNPs using the in-situ chemical reduction method on TiO_2 nanotubes, which is synthesised using an anodic oxidation process. Scanning electron microscopy was used to determine the structure, morphology, and mechanical activity of the electrode. It was present both inside and outside of TiO_2 nanotubes whose length and diameter were about 1.2 μm and 120 nm. The composition was constructed and used as an electrode of a non-enzymatic 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). Nano enzymatic glucose biosensors have exciting applications in catalysis and sensor areas [48].

In [49] work, their silver nanostructures were significantly stabilised by the Mercaptopropionic Acid (MPA), and Self Assembled Monolayer (SAM) biosensor detection limit for endotoxin *E.coli* was estimated at 340 pg./ml. We investigated biosensor selectivity in different experiments, taking endotoxin *B.abortus* as the second form of endotoxin contamination in our target samples (HBs-ag developed

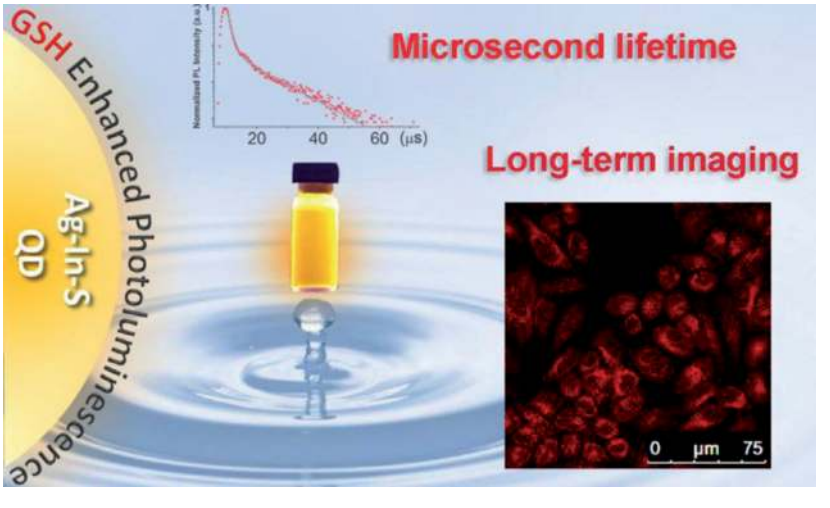

Figure 5.
Silver indium sulphide QDs stabilised by GSH and PET have been successfully prepared using an environmentally friendly and reproducible aqueous route. The resulting QDs have an absolute quantum yield (QY) photoluminescence (PL) of up to 37.2 percent [47].

at the Institute Pasteur, Iran). Overall, this study suggests that Localised Surface Plasmon Resonance (LSPR) biosensing can be considered in quality control laboratories as a sensitive, simple, and label-free method for detecting endotoxins. They showed that this biosensor could selectively detect both forms of endotoxins compared to other biological organisms. The construction of a silver-based LSPR biosensor for endotoxin detection was described. They used the Glancing Angle Deposition (GLAD) method to obtain reproducible nanocolumns of silver.

5. Environmental impacts, toxicity and disposal

The cytotoxicity of AgNPs must also be taken into account, particularly if used to treat chronic wounds. The wound healing and tissue repair mechanisms appear to be complex, and it is unknown if there is a temporary window on the exposure of AgNPs [15]. The toxicity of AgNPs depends on a variety of factors, such as concentration, duration, dosage and particle size. In comparison to (Michigan Cancer Foundation) MCF-7 cell culture, toxicity is dose-dependent and to cause cell damage in Human Epidermoid Larynx (Hep-2) cell line by Reactive Oxygen Species (ROS) formation. AgNPs biogenically synthesised from *Podophyllum hexandrum* leaf extract showed cytotoxicity and apoptotic influence, possibly through caspace-cascade activation and loss of mitochondrial integrity [50].

Metallic nanoparticles in general and AgNPs, in particular, are growing warning triggers for human and environmental managers due to the growing introduction of AgNPs into consumer goods. The enormous use of AgNPs in the products points out so many questions about the toxicity and safety [13]. Release of AgNPs from consumer goods is required to shift in land-based environments, but their fate and transition are very complicated and little are understood about their effect on the climate. AgNPs textile and cosmetic compounds in Europe have the highest environmental exposure when washing and rinsing water in wastewater treatment plants is treated. The resulting silver release from these plants is predicted to be low in the soil and surface waters.

However, owing to the widespread use of silver-based goods, the public is concerned about various aquatic lives when AgNPs reach the sea. Another concern with AgNPs is that they do not differentiate between helpful and harmful microorganisms. Free silver or AgNPs found in urban wastewater have been greatly converted into Ag_2S during the wastewater treatment process. There are several techniques available to regulate and reduce their toxicity by surface alteration. Surface modification is helpful in stabilising nanoparticles against agglomeration and keeping these nanostructures compliant with another step. The WHO has estimated 50% of the biological pollution indoor air is created by air handling systems and the production of harmless microorganisms such as bacterial and fungal pathogens has been observed in air filters. Most of these pathogens develop mycotoxin, which is harmful to human health, decreasing microbial growth in air filter by incorporating antimicrobial Ag-NPs through air filters.

The antimicrobial effect of Ag-NPs on bacterial contamination of activated carbon filters (ACFs) was investigated by [51]. The study found that Ag-deposited "ACF filters" effectively eliminated bioaerosols. Analysis of the antibacterial activity of the Ag-coated "ACF filters" revealed that there were two bacteria called "*Bacillus subtilis*" and *E. coli* is completely inhibited within 10 and 60 minutes, respectively. Polymer air filters made of polypropylene and silver nitrate ($AgNO_3$) were examined for bacterial survival [52]. The results indicated that the addition of antibacterial agent $AgNO_3$ to filter effectively prevented bacteria from colonised filter. The presence of the antimicrobial compound $AgNO_3$ in the filtration systems reduces the number of bacteria observed in Gram-negative and Gram-positive bacterial strains *Micrococcus luteus, Micrococcus roseus, Bacillus subtilis* and *Pseudomonas luteola*.

The significant reduction in bacterial pathogens' growth in silver-treated filters has made the antimicrobial filters therapy technology quite important for the future. Water is one of the most valuable substances on Earth and is necessary for all living beings. About 70 percent of the world is saturated with water, but just 0.6 per cent is suitable for human use. Access to clean water is a major health and social challenge in many developed countries. There has been considerable interest in water disinfection using AgNPs. Chemicals formed by nanosilver (chem-Ag-NPs) can be uniformly decorated on porous ceramic materials to form Ag-NPs-porous ceramic, composite materials using 3-aminopropyltriethoxysilane (APTES) as a molecule interaction [53]. Since silver and AgNP are commonly used in clinical fields, more study is required into the cytotoxic effects of normal cells and cancer cells. AgNPs have been observed as toxic to some of their mammalian cells. The IC50 was of 5 lg/mL (GT-AgNP) and 272.14 ± 0.09 lg/mL (C-AgNP), for example, in AgNPs (C-AgNP and GT-AgNP), synthesised with coffee and green tea extract. Besides, the susceptibility of NIH/3 T3 to the AgNPs was improved from cervical cancer, with IC50, 14.26 ± 0.05 lg/mL (GT-AgNP). AgNPs demonstrated cytotoxic effects by cell line and by the exposure concentration. Significantly cytotoxic activity against the cells of B16F10 (mouse melanoma; IC501/26.43 ± 3.4108 g/mL), SKOV3 (human ovarian, carcinoma; IC501/416.24 ± 2.4808 g/mL), A549 (human lung adenocarcinoma; IC501/43 ± 33978 g/mL) and PC3 (human prostate cancer; IC501/41 ± 28 g/mL) were observed in AgNPs synthesised with fungal *Pestalotiopsis microspora* (mL) [54]. The silver accumulation's major organs are the liver and kidney, irrespective of whether the AgNPs are intravenous, oral or nasal [36]. AgNPs from diverse resources has different impacts on the wellbeing of mammals. In vivo experiments in rats treated with 10 mg/kg AgNPs synthesised with *Ficus religiosa* leaf extract showed an accumulation of silver in the liver, brain and lungs at a concentration of 4.77, 3.94 and 3.043 μg/g of tissue respectively (In **Figure 6**) [55].

AgNPs are not only detrimental to humans; they are also harmful to fish. The toxicity in Zebrafish is measured. Suggested findings The LD50 for silver nitrate was 100 lg/L, but the LD50 was 80 and 400 lg/L for chemical and plant synthesis AgNPs, respectively [36]. Fungal-derived AgNPs did not significantly impact *Poecilia reticulate* after 48 h of exposure to 3.41 mg/L. This may mean that fungal-derived AgNPs are the least toxic among the numerous AgNPs, whereas chemical-derived AgNPs are usually more toxic than silver nitrates. AgNPs also possess size-dependent toxicity to Zebrafish. For example, smaller size AgNPs appear to cause higher mortality rates and lower hatchability rates, resulting in higher embryotoxicity than larger particle sizes [56]. The cytotoxicity of AgNPs is influenced by many factors, including shape, size, composition, surface charge, and capping molecule or coating. **Uncoated Ag NPs are more harmful than Ag NPs, which are coated. AgNPs should be kept in the dark at a temperature of 4 °C as they are photosensitive. AgNPs that are not properly stabilised can rapidly oxidise and easily mix in solutions** [57]**.**

5.1 Future concerns

Nevertheless, more research is still needed to explore the potential risks of inorganic metallic filler (e.g., AgNPs) towards ecological, human, and animal activities. Inorganic fillers are not biodegradable, and it varies with different synthesis approaches and methods for the quality. Hence, clay and calcium carbonate is the most common inorganic fillers used in research since they are usually environmental-friendly and inexpensive.

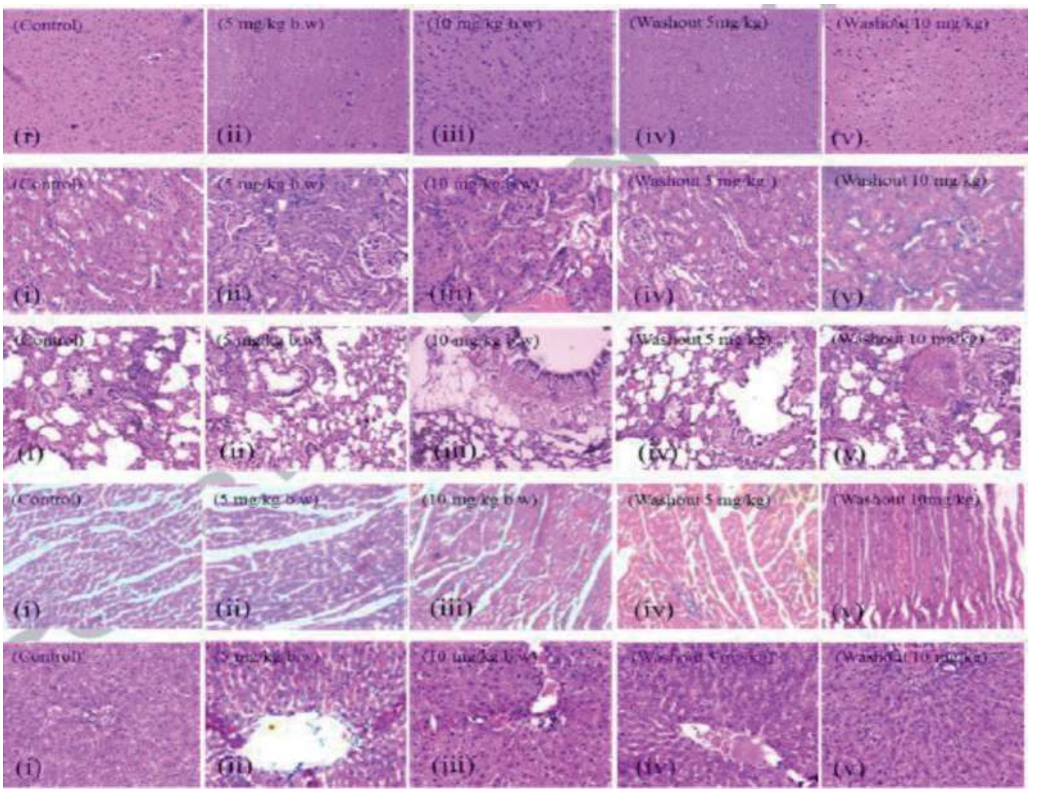

Figure 6.
No histopathological changes have been observed in the kidneys, brain, heart, lungs, and spleen from rats treated with FRAgNPs of 5 and 10 mg/kg b.w on day 29 as well as on day 89 [55].

6. Conclusion

The use of AgNPs as antibacterial agents must, therefore, be extended. Moreover, extensive research and development towards applying for multifunctional AgNPs and study on human health and the environment impacts are much needed. Then, the development of technology to prevent systemic side effects is also required. Numerous studies showed that AgNPs could slow down the viability of the antiviral activity's exact mechanism remains elusive and demand further testing. In future, the environmentally sustainable and advance approach of AgNPs synthesis could provide a viable alternative method to traditional physical and chemical methods.

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