International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Review Article)

Silver nanoparticles (AGNPs): A review on properties and behavior of silver at the nanoscale level

Victor Hammed *, Azeez Adedayo Bankole, Odetoran Akinrotimi and Oluwaseun Ayanleye

Nanotechnology, North Carolina A&T States University, Greensboro North Carolina, USA.

International Journal of Science and Research Archive, 2024, 12(02), 1267–1272

Publication history: Received on 18 June 2024; revised on 24 July 2024; accepted on 27 July 2024

Article DOI: https://doi.org/10.30574/ijsra.2024.12.2.1379

Abstract

Silver nanoparticles (AgNPs) have garnered significant interest due to their unique and enhanced properties compared to bulk silver. These nanoparticles exhibit remarkable chemical, physical, and biological characteristics, primarily attributed to their high surface area-to-volume ratio and nanoscale dimensions. Key properties include superior antibacterial, antiviral, and antifungal activities, potent catalytic capabilities, and distinctive optical properties, such as localized surface plasmon resonance (LSPR). These enhanced properties stem from the increased surface reactivity and quantum effects at the nanoscale. AgNPs are extensively applied across various fields. In medicine, they are utilized for their antimicrobial properties in wound dressings, coatings for medical devices, and as components in drug delivery systems. In environmental science, they serve as effective agents in water treatment processes due to their potent antimicrobial action. Additionally, AgNPs are employed in electronics for conductive inks, in catalysis for chemical reactions, and in textiles for producing antibacterial fabrics. The improved properties of silver nanoparticles over bulk silver are mainly due to the increased proportion of surface atoms, which leads to higher surface energy and reactivity. Furthermore, the nanoscale dimensions allow for quantum confinement effects, enhancing their optical and electronic properties. These unique characteristics enable AgNPs to perform more effectively and efficiently in various applications, making them a vital component in advancing technology and healthcare solutions.

Keywords: AgNPs- Silver nanoparticles; LSPR- Localized surface plasmon resonance; RhB- Rhodamine B; PCB- Printed Circuit Board; CO- Carbon Oxide; Smartsilver

1. Introduction

Silver nanoparticles (AgNPS) contain 20-15,000 silver atoms, generally smaller than 100nm and exhibit distinct biological, electronic, anti-bacterial, magnetic, chemical and physical properties in contrast to their parent (bulk) materials [1, 2]. The application of AgNPs in biomedicine rises on a quotidian basis and this has led to their overwhelmingly growing attention. The size and shape of silver nanoparticles strongly influence their catalytic, thermal and optical properties. Currently, a very crucial issue in many fields of research is the use of green chemistry to improve and protect our environment, and AgNPs has been influential to this feat. Also, the use of AgNPs in pharmaceutical application is a promising strategy to generate new fields in biomedical sciences [3].

Huge amount of hazardous gases and chemicals, adversely affecting our nature, are released into the environment due to the explosion of the world population and the advent of industrial era. However, the world is currently focusing on the development of natural products nanoparticles in order to avoid this and protect our nature.[4] Novel medicinal potential of silver has proven its antimicrobial potential from the ancient era.[5] Meanwhile, wide spectrum antibacterial potential was shown by AgNPs and its related products against sixteen bacterial species due to the fact that they are tremendously venomous [6, 7].

* Corresponding author: Victor Hammed

Furthermore, due to high surface area to volume ratio, nanoscale materials have emerged as novel "anti-microbial agents" exhibiting unequivocal physical and chemical attributes [8, 9]. AgNPs are vastly utilized in sterilizing nanomaterials both in consumer and medical products; for example, refrigerator surfaces, storage bags, personal care products, and textiles. Prime importance is gained by crystalline nano-silver as they consequently possess superior applicability in electronics, antibacterial, biomolecules, diagnostic applications in health care system etc. Researchers are still in search of answers as regards how to synthesize cost effective and eco-friendly tools to develop AgNPs, asides from its novel applicability [7, 10].

2. Properties of Silver Nanoparticles

Generally, silver nanoparticles have sizes ranging from 1 and 100nm size, exhibiting certain unique set of properties different from the parent material, such as magnetic, optical, antibacterial and electrical with a broad range of applicability. [11] Pure silver possesses relatively low contact resistance and high electrical and thermal conductivity, which makes it a sought-after choice in electronics. Nanowires or silver nanoparticles, however, have been utilized in fabricating thin-film transistor electrodes [12], as inks and pastes for printed circuit boards (PCB) [13], data storage devices, optoelectronics and battery-based intercalation materials [14].

AgNPs exhibit large surface area by virtue of their extremely small size, which proffers them high surface energy and openness to more reactive sites. This special attribute makes AgNPs a standout as one of the most prominent substances in catalysis. In combination with nanocomposites, they are magical at increasing the rate of several number of reactions, such as reduction of 4-nitrophenol to 4-aminophenol [15], reduction of Rhodamine B (RhB) [16], CO and benzene oxidation (11), and reduction of 4-nitrophenol in the presence of $NaBH_4$ [17].

In furtherance, asides these aforementioned attributes of AgNPs, some other unique and exciting properties are delineated below.

2.1. Optical Properties

A collective coherent oscillation of free electrons is induced by oscillating electromagnetic field of light when AgNPs are exposed to a specific wavelength of light. This consequently causes a separation of charge with respect to the ionic lattice, bringing about a dipole oscillation in the same direction to the light's electric field. At a specific frequency known as surface Plasmon Resonance (SPR), the amplitude of the oscillation reaches the peak. By controlling particle shape, size and refractive index near the surface of the particle, the scattering and absorption properties of AgNPs can be changed. For instance, small nanoparticles have peaks near 400nm and mostly absorb light, while nanoparticles that are larger have peaks that widen and move towards longer wavelength and they exhibit light scattering. When delocalization of the conduction electrons near the surface of the particle occurs due to particles aggregation, it has been observed that the optical properties can also change [18].

2.2. Antibacterial Effects

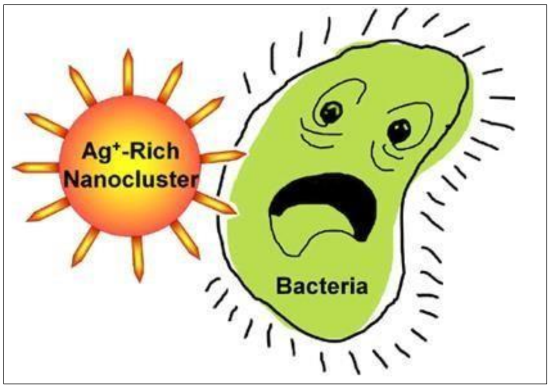

Figure 1 The antibacterial effect of AgNPs

In several applications such as biomedical devices, wounds and burns treatment, surgery applications and dental works, the control of bacterial growth has been carried out through the use of the antibacterial effects of silver nanoparticles. Introduction of AgNPs can lead to cell death by inducing a high degree of morphological and structural changes into bacterial cells due to the high degree of toxicity enveloped by silver-based compounds and silver ions towards microorganisms [19, 20].

2.3. Catalytic Properties

Catalytic redox properties have been demonstrated to be exhibited by AgNPs for chemical agents such as benzene, as well as biological agents such as dyes. The catalytic properties of AgNPs are greatly influenced by their chemical environment. Additionally, it is of great essentiality to know that complicated catalysis occurs by adsorption of the reactant species to the catalytic substrate. The catalytic property is usually diminished due to decreased adsorption ability when surfactants, complex ligands or polymers are utilized as stabilizers or in the prevention of coalescence of the nanoparticles. Generally, in chemical reactions, AgNPs are often used with titanium oxide as catalysts [21].

2.4. Applications

In ancient times, silver has been used for several purposes ranging from currency to jewelries to more modern applications in electronics, photographic appliances, automobiles and medicine where it has been utilized as an antiseptic for treating wound. As aforementioned, the improved properties possessed by nano-silver compared to their macro scale counterpart cannot be overemphasized as this is the major reason for their unparalleled usage in numerous applications, such as—water disinfectants, room sprays, cosmetic and medical devices, household and electrical appliances, odor resistant textiles, food supplements and food packaging materials [22, 23].

In fact, silver nanoparticles are claimed to be present in approximately 30% of consumer products.

For commercial products in the year 2009, the estimated worldwide market size of nano-silver was 320,000 kg per year [24], approximating to a market value of $290 million, even though the expectation is that by 2016, there will be a rapid expansion to $1.2 billion [22]. The appearance of this volume may be small, meanwhile, its toxicological burden might be 10,000 folds as great as these volume of bulk silver [25]. There has been unprecedented attention from public pressure groups and regulatory bodies of national governments as a result of the potential leaching of AgNPs from products. A good example of this instance is the neutralization of bacteria associated with foot odor through the addition of AgNPs to socks (e.g. SmartSilver or AgActive) [26].

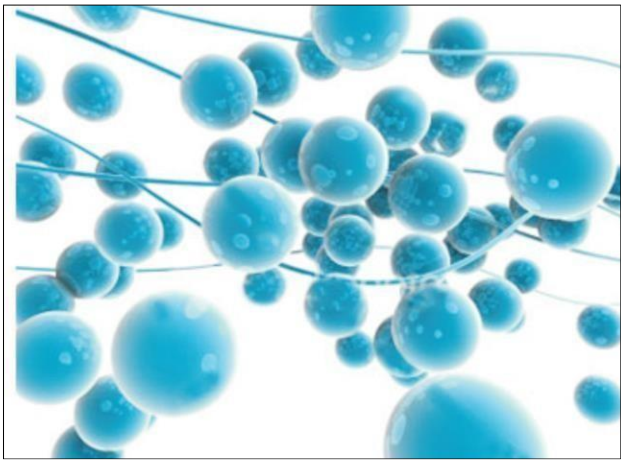

Figure 2 Nano-silver particles attached to fibres [22].

In a recent study by Benn et al. [27] it was revealed that during washing cycles, silver can easily leak into waste water, potentially causing danger to aquatic organisms in streams and lakes, or disrupting helpful bacteria used in waste-water treatment facilities. Some brands of socks have been reported to lose almost 100% of their silver content within four washings, while less than 1% were lost by two other brands over the same number of washings.

According to Vigneshwaran et al. [28] for enhanced antimicrobial activity, manufacturers of washing machines, such as Samsung and Daewoo are now incorporating nano-silver into their washing machines. Due to the possible risk of nano-sliver leaching into waste water stream, Swedish Environmental Protection Agency has wailed against this particular application. This infers that one must exercise caution in the use and application of nano-silver for now, even though the nano-silver-containing products seem to be on the high rise.

The potential replacement of nano-silver with Indium tin oxide (ITO), which is a rampantly utilized transparent conductive oxide employed in photovoltaic cells and display devices, is another possible application that is currently being researched by industrial companies and academics [22]. As reported by Zhi Zhang et al., [3] AgNPs are very versatile in commercialization applications such as in medicinal devices, textile industries, food storage and healthcare products. They are also used as disinfectants in water treatment to home appliances and medical devices due to their antibacterial agents.

Recently in 2021, Sonika et al. [29] also studied myriad applications of silver nanoparticles. It was discovered that they act as excellent heterogeneous catalyst utilized for the decrease of organic pollutants that are halogenated [30]. They also assist in improving organic dye's bleaching power. AgNPs that are tubular-shaped exhibit incredible level of catalytic activity, thus, can be utilized as catalysts. Also, AgNPs that are biosynthesized on nitrocellulose membrane filters are used in water treatment by deactivating and inhibiting microbes like Enterococcus faecalis and E. coli, etc. They also reported that AgNPs can be used as preservatives in agricultural and food products, as much as they are versatile antimicrobial agents.

3. Conclusion

In recent years, there has been tremendous progress in the research on AgNPs application and investigation of its properties. Due to the unique set of properties displayed by AgNPs, they are widely used in growing number of applications. Meanwhile, there is possibility of their release into the environment due to the accelerating introduction of AgNPs into commercial products, consequently giving rise to environmental and health concerns. However, this paper focuses on introduction, properties, past and current researches, and applications of AgNPs.

It is clearly known that various products have AgNPs incorporated in them. Hence, since it has been reported that the nanoparticle release is greatly affected by the type of incorporation [31]. Additional research should be meticulously carried out to decipher the strength of bonds between AgNPs and products. On the other hand, most of the products containing AgNPs do not provide details of concentration, type of incorporation, capping agent, shape, and size. Thus, to reduce the potential adverse effects of AgNPs, policy makers are advised to regulate the market.

Although in recent years, immense progress has been made in monitoring AgNPs and a great number of techniques is available to quantify and characterize AgNPs. Nonetheless, tracking AgNPs in the environment is still a herculean task because it is beyond the detection capability of most instruments as the amount of nano-silver in the environment is extremely small. In order to carry out full investigation as regards the fate and transport of AgNPs in the environment, appropriate methods for speciation, separation and preconcentration of AgNPs should be developed, and also needed are analytic tools for the detection and characterization of AgNPs in complicated biological and environmental samples.

Once AgNPs are released into the environment, their relatively high surface energy resulting from their large surface area could make the particles highly dynamic, bringing about an easy occurrence of different transformations such as chlorination, sulfurization, aggregation and oxidation—which in return affects the behavior of the AgNPs greatly. Thus, environmental transformation in relation to the stability and toxicity of AgNPs should be thoroughly investigated.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] De Gaetano, F., et al., Sol-gel processing of drug delivery materials and release kinetics. Journal of Materials Science: Materials in Medicine, 2005. 16(3): p. 261-265.

[2] Crabtree, J.H., et al., The efficacy of silver-ion implanted catheters in reducing peritoneal dialysisrelated infections. Peritoneal Dialysis International, 2003. 23(4): p. 368-374.

[3] Galatage, S.T., et al., Silver Nanoparticles: Properties, Synthesis, Characterization, Applications and Future Trends, in Silver Micro-Nanoparticles-Properties, Synthesis, Characterization, and Applications. 2021, IntechOpen.

[4] Bar, H., et al., Green synthesis of silver nanoparticles using latex of Jatropha curcas. Colloids and surfaces A: Physicochemical and engineering aspects, 2009. 339(1-3): p. 134-139.

[5] Suh, W.H., et al., Nanotechnology, nanotoxicology, and neuroscience. Progress in neurobiology, 2009. 87(3): p. 133-170.

[6] Slawson, R.M., J.T. Trevors, and H. Lee, Silver accumulation and resistance in Pseudomonas stutzeri. Archives of microbiology, 1992. 158(6): p. 398-404.

[7] Zhao, G. and S.E. Stevens, Multiple parameters for the comprehensive evaluation of the susceptibility of Escherichia coli to the silver ion. Biometals, 1998. 11(1): p. 27-32.

[8] Morones, J.R., et al., The bactericidal effect of silver nanoparticles. Nanotechnology, 2005. 16(10): p. 2346.

[9] Helenius, A., Fields "Virology" Fifth Edition: Virus Entry and Uncoating. LWW: London, UK, 2007: p. 99-118.

[10] Królikowska, A., et al., SERS studies on the structure of thioglycolic acid monolayers on silver and gold. Surface science, 2003. 532: p. 227-232.

[11] Klaus, T., et al., Silver-based crystalline nanoparticles, microbially fabricated. Proceedings of the National Academy of Sciences, 1999. 96(24): p. 13611-13614.

[12] Tate, J., et al., Anodization and microcontact printing on electroless silver: Solution-based fabrication procedures for low-voltage electronic systems with organic active components. Langmuir, 2000. 16(14): p. 6054-6060.

[13] Li, Y., Y. Wu, and B.S. Ong, Facile synthesis of silver nanoparticles useful for fabrication of highconductivity elements for printed electronics. Journal of the American Chemical Society, 2005. 127(10): p. 3266-3267.

[14] Tolaymat, T.M., et al., An evidence-based environmental perspective of manufactured silver nanoparticle in syntheses and applications: a systematic review and critical appraisal of peerreviewed scientific papers. Science of the total environment, 2010. 408(5): p. 999-1006.

[15] Naik, B., et al., Synthesis of Ag nanoparticles within the pores of SBA-15: an efficient catalyst for reduction of 4-nitrophenol. Catalysis Communications, 2011. 12(12): p. 1104-1108.

[16] Ai, L., C. Zeng, and Q. Wang, One-step solvothermal synthesis of Ag-Fe3O4 composite as a magnetically recyclable catalyst for reduction of Rhodamine B. Catalysis Communications, 2011. 14(1): p. 68-73.

[17] Manesh, K.M., et al., Silver nanoparticles distributed into polyaniline bridged silica network: A functional nanocatalyst having synergistic influence for catalysis. Catalysis Communications, 2010. 11(10): p. 913-918.

[18] Yu, S.-j., Y.-g. Yin, and J.-f. Liu, Silver nanoparticles in the environment. Environmental Science: Processes & Impacts, 2013. 15(1): p. 78-92.

[19] Birla, S., et al., Fabrication of silver nanoparticles by Phoma glomerata and its combined effect against Escherichia coli, Pseudomonas aeruginosa and Staphylococcus aureus. Letters in Applied Microbiology, 2009. 48(2): p. 173-179.

[20] Li, W.-R., et al., Antibacterial effect of silver nanoparticles on Staphylococcus aureus. Biometals, 2011. 24(1): p. 135-141.

[21] Ye, Q., et al., Nanosized Au supported on three-dimensionally ordered mesoporous β-MnO2: Highly active catalysts for the low-temperature oxidation of carbon monoxide, benzene, and toluene. Microporous and Mesoporous Materials, 2013. 172: p. 20-29.

[22] McINTYRE, R.A., Common nano-materials and their use in real world applications. Science progress, 2012. 95(1): p. 1-22.

[23] Wijnhoven, S.W., et al., Nano-silver–a review of available data and knowledge gaps in human and environmental risk assessment. Nanotoxicology, 2009. 3(2): p. 109-138.

[24] Gottschalk, F., et al., Possibilities and limitations of modeling environmental exposure to engineered nanomaterials by probabilistic material flow analysis. Environmental toxicology and chemistry, 2010. 29(5): p. 1036-1048.

[25] Maynard, A.D., Nanotechnology: a research strategy for addressing risk. 2006.

[26] Birch, H., ''Silver Soils'', Birch, H. (2012) Chem. World, February 2012, 36 – 39. ''Silver Soils'', Birch, H. (2012) Chem. World, February 2012, 36 – 39., 2012.

[27] Benn, T.M.a.W., P. (2008). , Benn, T.M. and Westerhoff, P. (2008). Environ. Sci. Technol., 42, 4133 –4139; Erratum, 42, 7025– 7026. Benn, T.M. and Westerhoff, P. (2008). Environ. Sci. Technol., 42, 4133 –4139; Erratum, 42, 7025–7026.

[28] Vigneshwaran, N., et al., Functional finishing of cotton fabrics using silver nanoparticles. Journal of nanoscience and nanotechnology, 2007. 7(6): p. 1893-1897.

[29] Dawadi, S., et al., Current research on silver nanoparticles: Synthesis, characterization, and applications. Journal of Nanomaterials, 2021. 2021.

[30] Hammed Victor., Solubility of CO2 in Paramagnetic Ionic Liquids, North Carolina Agricultural and Technical State University ProQuest Dissertations Publishing, 2023. 30419527.

[31] Geranio, L., M. Heuberger, and B. Nowack, The behavior of silver nanotextiles during washing. Environmental science & technology, 2009. 43(21): p. 8113-8118.