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Silver nanoparticles (Ag-NPs): Synthesis and application

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Abstract
Recently, the silver nanoparticles (Ag-NPs) material is gaining interest among a number of metallic nanoparticles, with several applications in fields such as catalysis, electronics, biomedicine, health food or in fabrication of antibacterial materials. This article provides readers with information about the synthesis, characterization, and application of Ag-NPs.

Keywords: Silver nanoparticles (Ag-NPs); synthesis; characterization; antibacterial; applications.

1. Introduction
Nanoparticles (NPs) are clusters of atoms in the size range of 1 - 100 nm. “Nano” is a Greek word synonymous to “dwarf” meaning extremely small. The use of NPs is gaining impetus in the present century as they possess original properties, at the frontier between molecular and metallic state [1]. For example, gold (Au), silver (Ag) and cupper (Cu) NPs exhibit bright and gaudy colors that are not observed for the bulk metal. It is now well understood that the intrinsic characteristics of these NPs are dependent on their composition, size, crystallinity, shape, and structure. Although they are mainly used in sensing and imaging applications due to the optical properties, NPs found also other important applications for example as antimicrobial or in electrical conducting applications [2].

In recent years, silver nanoparticles (Ag-NPs) have been extensively studied due to their outstanding physical, chemical and biological properties. The preeminent properties of silver nanoparticles (Ag-NPs) are mainly derived from the size, shape, composition, crystallinity and structure of the nano-state compared with the bulk form of silver material [3–6]. One important property of silver nanoparticles is their antibacterial ability against a wide range of pathogenic organisms. It was proposed that the antibacterial activity of Ag-NPs depends on their size [7]. When Ag-NPs are small and release many Ag ions, the antibacterial activity is dominated by these ions.

However, when relatively large (mean diameter > 10nm) Ag-NPs are employed, the concentration of released Ag^+ is lower, and the particles themselves are responsible for antibacterial activity. For example, colloidal silver particles, with variable sizes (44, 50, 35, and 25 nm), synthesized by the reduction of $[Ag(NH_3)_2]^+$ complexes with carbohydrates were tested for antimicrobial activity. The antibacterial activity was particle size dependent. The silver nanoparticles also exhibit a shape-dependent interaction with the bacterial cells. The truncated triangular silver nano-plates displayed the strongest biocidal action against E. coli, then the spherical and rod-shaped nanoparticles [8]. This paper presents a comprehensive overview of Ag-NPs synthesis by different methods, their characterization and applications.

2. Reduction method for synthesis of Ag-NPs
The common methods for Ag-NPs synthesis is reduction of a silver ion compound. The silver ions in $AgNO_3$ or $AgClO_4$ salts, is reduced to silver colloidal component in the presence of a reducing agent. According to the references [9-10], when the concentration of silver ions increases enough, dissolved metallic silver ions combine together to create a stable surface. By reacting with the reducing agents, cluster of silver nanoparticles is formed. The cluster of Ag-NPs obtains a certain size, called as the critical radius. In this size state, the silver nanoparticles have a favorable energy to continue to grow. There are many different reducing agents in this synthetic method, including the sugars, citrate, polyol, ascorbate, hydrazine, N-dimethylformamide, dextrose, sodium borohydride [11-12]. An

example of the reducing reaction by ($NaBH_4$) is described by the following reaction: $Ag^+ + BH_4^- + 3 H_2O \rightarrow Ag^0 + B(OH)_3 + 3.5 H_2$. Sodium borohydride $NaBH_4$ is a strong reducing agent. Therefore, the advantage of using this reducing compound is the increase of dispersion of the synthetic nanoparticles.

The polyol method is a typical process for Ag-NPs synthesis because it can control the size and shape of the synthetic nanoparticles [13-14]. The polyol process begins by the heating of ethylene glycol or propylene glycol. A salt containing Ag^+ ions and a stabilizing agent (usually PVP) are put into the reactive mixture. The Ag^+ ions are then reduced by the polyol compound to form the colloidal nanoparticles. The polyol method is very sensitive to reactive conditions such as temperature, pH, and concentration of components in the reactive mixture. Therefore, the change of reactive conditions can lead to obtaining different sizes and shapes of Ag-NPs such as spheres, stars, pyramids, rods, triangles, and wires. The polyol reducing reaction can be presented as the following reaction: EG + Ag^+ + PVP → Stabilizer (PVP) + Ag^0 (nanoparticles).

A very common method for synthesizing Ag-NPs is citrate reduction [15-16]. The advantage of citrate agent is that it both acts as a reducing agent and also acts as a structural stabilizer. The trisodium citrate $Na_3C_6H_5O_7$ is widely used for the reduction of silver salts to form colloidal silver nanoparticles. The synthesis is usually done at high temperature in the range of 60 - 100 °C to speed up the reduction reaction to create uniformity in both size and shape of Ag-NPs. However, the citrate compound is a weak reducing agent, synthetic Ag-NPs particles may have wide and uneven size distribution. Therefore, this synthesis process is often added with stronger reducing agents to speed up the reaction, creating Ag-NPs with more uniform size and shape.

Besides the methods introduced above, the silver nanoparticles can be synthesized by other methods such as monosaccharide reduction, seed-mediated growth, ion implantation, silver mirror reaction, and biological synthesis [15-17].

3. Characterization of Ag-NPs

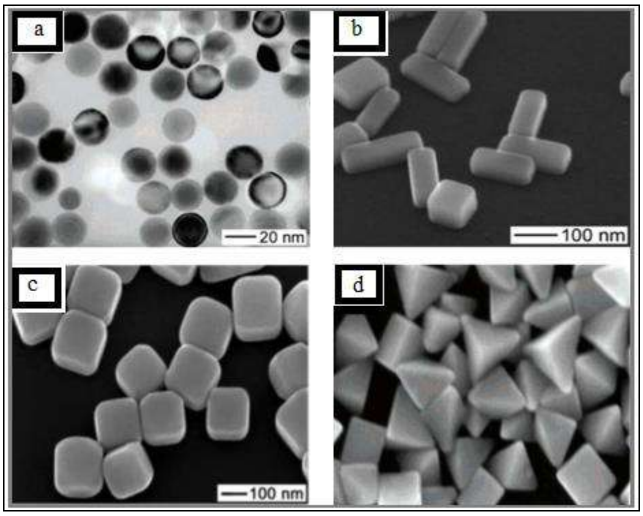

Fig 1: TEM observation of Ag-NPs at different morphologies a) Ag-NPs spheres [18]; b) Ag-NPs nanobars [19] c) Ag-NPs nanocubes [20] d) Ag-NPs pyramids [21].

The synthesis by different routes can lead the formation of NPs with variety of sizes, shapes and surface chemistry. The obtained NPs can be characterized by state of the art techniques such as electron microscopy, X-Rays diffraction, dynamic light scattering, UV-Vis spectroscopy. In detail, Ag-NPs size and morphology can be investigated by transmission electron microscopy (TEM) as seen in the Figure 1.

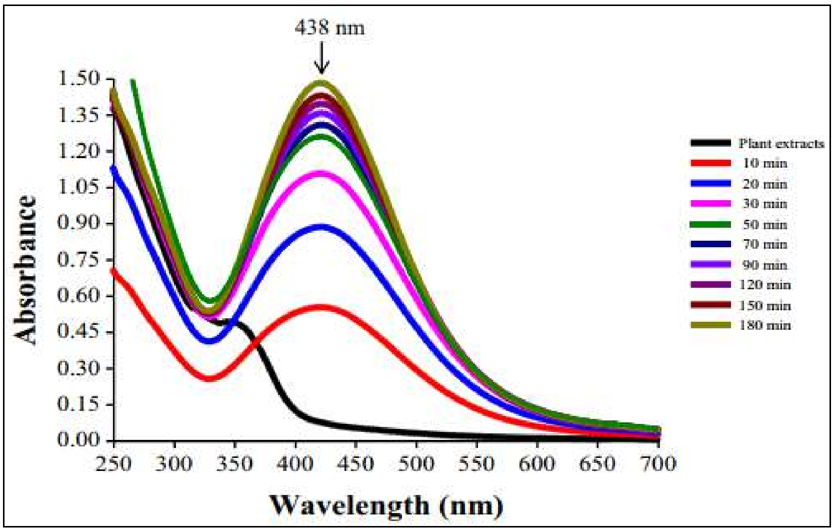

Fig 2: UV-Vis spectra of Ag-NPs synthesized by green processing at different times [22].

The properties of Ag-NPs solutions can be studied by using UV-Vis spectroscopy, following the absorption maxima at about 460 nm due to surface plasmon-resonance of silver NPs. Figure 2 presents the UV-Vis spectra of Ag-NPs synthesized by green processing at different times [22]. Other characterizing methods such as X-ray diffraction (XRD), Dynamic light scattering (DLS), Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS),

Scanning electron microscopy (SEM), and Atomic force microscopy (AFM) can be used to complete the investigation of Ag-NPs.

4. Application of Ag-NPs

Silver nanoparticles (Ag-NPs) can be used in several applications such as catalysis, dye treatment, gas sensor, light-enhancement, chemotherapy, antimicrobial – antibacterial, surface-enhanced fluorescence, biomedical, optoelectronics, or adding to daily goods [17].

5. Conclusion

This scientific paper would provide the readers with main information on the synthesis, characterization and applications of silver nanoparticles (Ag-NPs). The typical methods for Ag-NPs synthesis was firstly presented. Next is the presentation of Ag-NPs characterization. Finally, some applications of Ag-NPs were succinctly described.

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