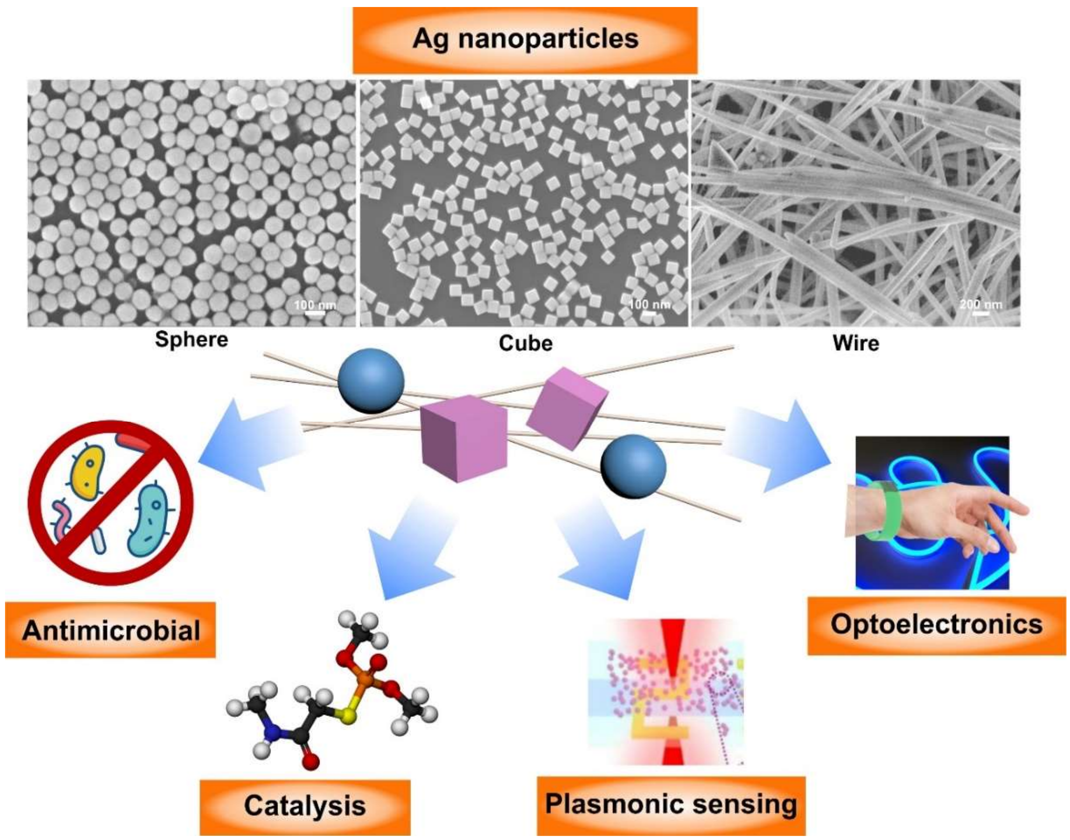
Application Note

An emerging material for the new decade: Silver nanoparticles and their applications

Introduction

Silver nanoparticles are gaining immense attention in the global material market, accounting for USD 792.1 million in 2014 and expected to quadruple and hit USD 3 billion by 2024.[1] As a relatively "young" nanomaterial, this class of nanoparticles are sprouting its breakthrough as the most highly sought-after material in multiple industries across all key industrial sectors including *textiles, food and beverages, healthcare,* and *electronics*. Thus, the new decade 2020 – 2030 will also witness the bloom of silver nanoparticles alongside nanotechnology, as it reigns over conventional bulk-scale technology in the aforementioned industries. This article introduces a few morphologies of silver nanoparticles, highlights their key applications and provides insights into how they are disrupting various technologies in the coming decades.



Different morphologies of silver nanoparticles and their key applications.

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SILVERFACTORY TECHNOLOGY

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1. Silver nanospheres

Silver nanospheres are the most basic and easiest-to-synthesize silver nanoparticles, possessing arbitrary sphere-like morphology and typically available in multiple sizes < 100 nm. They can be easily synthesized using either top-down etching of bulk material/large particles or bottom-up seed-growth methods, silver nanospheres are the most globally distributed and utilized class of silver nanoparticles. There are a wide range of modern technologies that contain/make use of silver nanospheres. Here, we feature three of the most popular applications of silver nanospheres.

- *Antimicrobial materials*: This is one of the most popular applications of silver nanospheres, arising from their chemical cytotoxicity and high surface area in releasing silver ions which degrade cells.[2] Regarded as nature's most powerful biocide, silver nanospheres can also attach to the bacterial cells, penetrate or cause structural changes to the cell membranes, thus killing targeted harmful microbes. Owing to such unique properties, silver nanospheres are emerging in the food and healthcare sectors, mainly applied as anti-cancer and anti-bacterial coating materials for food packaging, medical device and biomedicine. Furthermore, they have been applied in therapeutic methodologies for cancer/disease treatments, and clinical items, such as bandages, wound dressings and dental resins.[3]
- *Optoelectronics*: In general, silver nanospheres are excellent light absorbers and scatterers due to the collective oscillation of conduction electrons upon interaction with excitation light at specific wavelengths (surface plasmonic resonance, SPR). Coupled with their extraordinary conductivity and thermal stability, silver nanospheres have found use in various optoelectronic devices, such as smart glass, touchscreens, LED and OLED displays, and etc.[4]
- *Catalysis*: At 50-fold cheaper than gold (Au) and 25-fold cheaper than palladium (Pd), silver nanospheres display pronounced catalytic properties in heterogeneous reactions due to their abundant reaction vacant sites. Silver nanospheres have been utilized in various academic and industrial organic reaction processes, such as nitroaromatic reduction, Friedel-Crafts and Diels-Alder reaction, reporting up to 100% conversion rate and > 95% stereoselectivity.[5]

2. Silver nanocubes

Silver nanocubes are shape-controlled cubic silver nanoparticles with well-defined tips and edges that condense electromagnetic field much more efficiently than edgeless silver nanospheres. The synthesis protocol for such shape-controlled particles are more stringent and sophisticated than that for nanospheres, therefore giving rise to homogeneity in both morphology and size distribution. Silver nanocubes essentially possess all the properties of nanospheres and can be applied for the aforementioned antimicrobial, optoelectronics and catalytic applications. In this article, we would like to highlight the signature plasmonic sensing performance of silver nanocubes, namely in surface enhanced Raman scattering (SERS) analysis.

- *Plasmonic sensing*: Silver nanocubes support multiple localized surface plasmon resonance (LSPR) modes when interacting with incoming light. This generates plasmonic hotspots which effectively concentrate electromagnetic fields at/near the metallic surfaces up to 10^5-fold. This enhanced electromagnetic field significantly amplifies the Raman scattering molecules near the metal surface, resulting in SERS effect. Unlike spherical nanospheres, silver nanocubes exhibit sharp edges and tips, which give rise to more intense electromagnetic field enhancement via "lightning rod effect".[6]

To further boost the electric field, silver nanocubes can also be assembled into a close-packed array with interparticle separation of < 10 nm.[7] Neighboring silver nanocubes in proximity undergo plasmonic coupling to create a very intense electromagnetic field confined at the interparticle gaps between adjacent particles. Collectively, silver nanocubes and their assembled platforms have demonstrated the capability to create electromagnetic fields capable of enhancing SERS signals by >10,000,000 time. The ability to support multiple LSPRs implies that our silver nanocubes are compatible with multiple common laser excitation wavelengths, i.e. 532 nm, 633 nm or 785 nm, for SERS measurements. Hence, silver nanocube-based SERS platforms have demonstrated parts-per-billion (ppb) and parts-per-trillion (ppt) detection of various molecules. They are highly promising for wide range applications in the field of analysis and sensing across different sectors, such as food quality control, medical diagnosis and atmospheric monitoring.

3. Silver nanowires

Silver nanowires exists as one-dimensional (1D) micrometer-long structures with typical aspect ratio greater than 10.[8] On top of the applications described for silver nanospheres and nanocubes, silver nanowires also feature uniquely attractive properties to be applied in flexible optoelectronics.

- *Flexible optoelectronics:* Silver nanowires exhibit optical and electronic activity over micrometer dimensions and are able to propagate plasmons across their longitude length. For application in optoelectronics, silver nanowires are generally assembled into a thin film. Such silver nanowire thin film demonstrates extraordinary flexibility while maintain its intrinsic (opto)electronic properties under mechanical stress.[4] As such, silver nanowires have been widely used for the production of wearable materials that can tolerate mechanical deformation (folds and bends), and have been used as the core base layer of touchscreens, LED and OLED displays.

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