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Silver Nanoparticles in Point-of-Care Diagnostics: Enhancing Sensitivity, Selectivity, and Future Prospects

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ABSTRACT.

Silver nanoparticles (AgNPs) have emerged as indispensable nanomaterials for point-of-care (POC) medical diagnostics, due to their unique optical, electrical, and chemical properties that enhance sensor sensitivity, selectivity, and stability. This review systematically discusses the fundamental physicochemical characteristics of AgNPs, with emphasis on surface plasmon resonance (SPR) and its role in signal amplification in techniques such as surface-enhanced Raman spectroscopy (SERS), electrochemical biosensors, and immunosensors. Special attention is given to how synthesis strategies, including chemical, physical, and green, affect nanoparticle uniformity, biocompatibility, and functionalization potential. The review also compares surface modification approaches, including polymer coatings for stability, aptamer/antibody conjugation for specificity, and core–shell architectures for fluorescence enhancement, highlighting their impact on biomarker detection in complex biological matrices. By critically analyzing current challenges such as aggregation, oxidation, and nonspecific binding, the paper synthesizes recent advances in antifouling strategies, scalable production, and integration of AgNPs into portable and wearable diagnostic platforms. Unlike previous reviews, this work consolidates developments across synthesis, surface chemistry, and device engineering, and provides a forward-looking perspective on multiparametric and theragnostic applications. Overall, the paper underlines the importance of multidisciplinary collaboration to accelerate the translation of AgNPs-based sensors into clinically viable POC technologies for personalized healthcare and early disease detection.

Keywords: silver nanoparticle; sensor; point-of-care; biomarker.

1. Introduction

Modern healthcare systems now rely primarily on point-of-care (POC) medical diagnostics, which provide fast, on-site identification of illness and biomarkers without requiring sophisticated laboratory equipment [1]. Especially in critical or remote environments, this strategy significantly reduces the time between sample collection and diagnosis, allowing medical practitioners to make quick, well-informed decisions that could enhance patient outcomes [2]. Significant research and development in this area have been driven by the growing need for accurate, affordable, readily available diagnostic instruments [3].

But three fundamental performance criteria, including sensitivity, selectivity, and stability, determine most of the POC diagnostic gadget's efficacy and dependability [4]. Particularly important for early-stage illness detection, when biomarker concentrations are typically extremely low, sensitivity is the device's capacity to detect minute amounts of target analytes. Selectivity ensures that the diagnostic method can effectively separate the target molecule from interfering compounds in complex biological samples such as urine, saliva, or blood [5]. Conversely, stability refers to the device's ability to maintain consistent performance over time and across many environmental variables, including temperature variations and humidity, which are common challenges in field applications [6].

Nanotechnology is emerging as a revolutionary approach to improve these crucial features in POC diagnostics. Due to their unique optical, electrical, and chemical properties among various nanomaterials, silver nanoparticles (AgNPs) have garnered considerable interest[7], [8], [9]. A substantial increase in electromagnetic fields at the nanoparticle surface is made possible by surface plasmon resonance (SPR) [10], among other key characteristics. In optical

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biosensors, including surface-enhanced Raman scattering (SERS), this phenomenon may amplify detection signals [10], thereby significantly increasing sensitivity. By enabling selective target identification [11], the great specific surface area of AgNPs also facilitates simple surface functionalization with biomolecules such as antibodies [12], aptamers [13], [14], or peptides [15], thereby improving the selectivity of biosensors.

Moreover, developments in surface modification and nanoparticle production have helped address stability issues with silver nanoparticles, particularly their oxidation and aggregation sensitivity.

The many ways in which silver nanoparticles could improve sensitivity, selectivity, and stability in POC medical diagnostics are thoroughly investigated in this paper. We begin by reviewing the basic physicochemical characteristics of AgNPs relevant to biosensing applications, followed by an in-depth examination of their integration into various diagnostic systems. We next discuss existing issues, including biocompatibility and manufacturing scalability, and conclude with future perspectives that underscore ongoing advancements poised to accelerate the use of AgNPs-based POC devices in clinical practice.

2. Theoretical Background

The remarkable optical characteristics of silver nanoparticles (AgNPs) that promote their application in point-of-care (POC) diagnostics are mainly driven by the surface plasmon resonance (SPR) phenomenon [16]. Because of its significant color changes and functional importance, which form the basis for rather sensitive analytical techniques, such as colorimetric assays [17] and surface-enhanced spectroscopies[10] Surface Plasmon Resonance (SPR) results from the collective oscillation of conduction electrons at the surface of metallic nanoparticles under a specific wavelength stimulus [18]. The physical characteristics of the nanoparticles, including their size, shape, and surrounding dielectric medium, have a major impact on this resonance, leading to significant light absorption and dispersion [19]. Light interaction with AgNPs may produce surface plasmon resonance (SPR), in which case the resonance is limited to the surface of the nanoparticle, therefore offering enhanced sensitivity to changes in the surrounding environment, an ideal feature for biosensing applications [20].

As illustrated in Figure 1, the oscillating electric field of the incident light induces a shift in the electron cloud relative to the positively charged atomic cores of the nanoparticle. This polarization leads to the development of dipoles and a resonance condition, which is highly sensitive to the local dielectric environment characteristic of SPR phenomena.

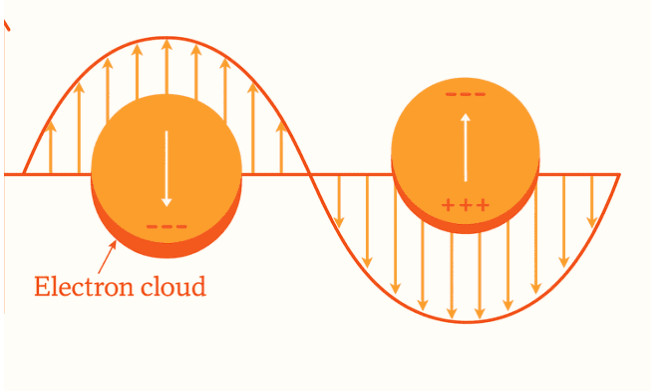

Figure 1. Schematic representation of surface plasmon resonance (SPR) on a metallic nanoparticle induced by an oscillating electric field. The electron cloud shifts in response to the electromagnetic wave, generating dipoles and enabling resonance with light of a specific wavelength [21].

Empirical studies have shown that particle size significantly affects the SPR peak wavelength of spherical AgNPs [22]. About seven nm-diameter particles show an SPR absorption peak at 400 nm. The SPR peak shifts red as particle size increases: 29 nm particles show an SPR peak about 425 nm, whereas 89 nm particles move to roughly 490 nm and provide a greenish hue [23]. Emphasizing the direct link between nanoparticle size and SPR features, the changes are not simply surface effects; they also reveal subtle variations in electron density and oscillation patterns on the particle surface [24] as shown in Figure 2.

The refractive index of the surrounding medium influences the position of the SPR peak. Characteristic of localized surface plasmon resonance (LSPR)-based biosensors for the real-time detection of molecule binding events, a higher local refractive index near the nanoparticle surface generates a red shift in the surface plasmon resonance (SPR) peak[25]. Even among nanoparticles of similar size and shape, variations in synthesis techniques, such as chemical reduction using different agents (e.g., glucose versus

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NaOH), can influence SPR performance. AgNPs made from glucose reduction, for example, frequently show SPR peaks at 400 nm, whereas those made from NaOH show peaks around 420 nm. This difference is linked to complex changes in surface chemistry and particle stability, which affect the optical response[23].

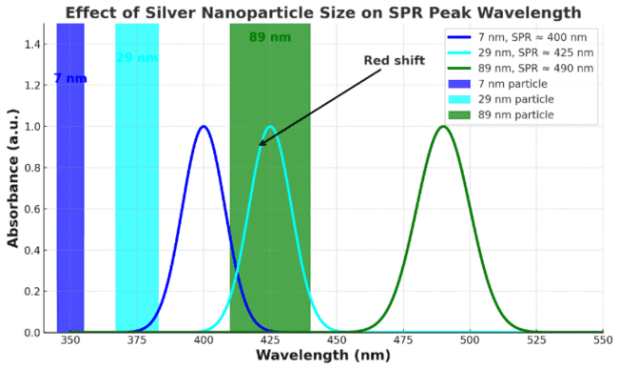

Figure 2. Effect of silver nanoparticle size on surface plasmon resonance (SPR) peak wavelength. As particle diameter increases from 7 nm to 89 nm, the SPR absorption peak shifts toward longer wavelengths (a red shift), altering the nanoparticles' optical properties and color. This shift results from changes in the nanoparticle's electron density and surface oscillation patterns.

Multiple interrelated factors, including electron density, retardation effects, and electron-electron scattering, influence the red shift in SPR with increasing nanoparticle size. Specifically, as particle size or temperature increases, SPR tends to shift to longer wavelengths, highlighting their dependence on both physical dimensions and thermal conditions [26], [27], [28]. Increased electron density during nanoparticle formation has also been linked to SPR red-shifts. Furthermore, retardation effects become dominant beyond 8–10 nm, altering the physical origin of the red shift [29]. At smaller scales, enhanced electron-electron and electron-phonon scattering rates further contribute to nonlinear red-shift behavior and broadening of the SPR band [27].

3. Methods

3.1. Synthesis Methods

Chemical, physical, and green (biological) methods of synthesis for silver nanoparticles (AgNPs) each have benefits depending on the intended use. Among them, chemical reduction remains the most widely used method, as its simplicity and good control over nanoparticle size and morphology typically yield quasi-spherical particles in the 10–100 nm range. Common reducing agents include sodium borohydride ($NaBH_4$) [30], trisodium citrate [31], and ascorbic acid [32]; stabilizing agents, polyvinylpyrrolidone (PVP) [33] and citrate helps minimize aggregation and assure colloidal stability. For example, Zhang et al. synthesized AgNPs using trisodium citrate and PVP, therefore producing a uniform size distribution suited for sensor functionalization [34]. Despite its high yield and reproducibility, this method may introduce chemical residues from reducing or stabilising agents, which can be problematic for biomedical applications. For example, Zhang et al. synthesised AgNPs using trisodium citrate and PVP, resulting in a uniform size distribution suitable for sensor functionalisation.

Physical approaches such as evaporation–condensation and laser ablation typically produce spherical AgNPs ranging from a few nanometres to several tens of nanometres, with the advantage of high chemical purity. In laser ablation in liquid (LASiS), particle size can be tuned by adjusting laser fluence and irradiation time, yielding relatively narrow size distributions. Unlike chemical synthesis, these methods do not require external capping or stabilising agents; however, the solvent itself often plays a role in short-term stabilisation. The main challenges are the need for specialised equipment, lower yields compared to wet-chemical synthesis, and difficulties in achieving long-term colloidal stability [34].

Green synthesis employs plant extracts, bacteria, or other biological agents as both reducing and stabilising agents, generally producing polydisperse spherical or anisotropic AgNPs in the 5–100 nm range. While this method is environmentally friendly and avoids toxic byproducts, it often suffers from limited control over particle morphology and batch-to-batch reproducibility due to variability in biological precursors.

3.2. Functionalization of AgNPs

The functionalization of silver nanoparticles (AgNPs) represents a significant advancement in the design of biosensors for medical diagnostics, particularly by increasing specificity and sensitivity

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towards disease biomarkers. By altering AgNPs' surface chemistry with selective ligands, such as polymers, biological recognition elements, or thiol-containing compounds, researchers can direct AgNPs to interact selectively with target analytes.

The following are key approaches of silver nanoparticle functionalization:

3.2.1. Polymer and Surface Coating for Stability

To prevent aggregation and oxidation of AgNPs in biological environments, stabilizers such as polyvinylpyrrolidone (PVP) [35] and branched polyethyleneimine (BPEI) are commonly employed. These offer steric or electro steric stabilization and preserve colloidal integrity even under high ionic strength. However, coating thickness must be optimized, as it can hinder signal generation, particularly in electrochemical setups.

Teengam et al. [32] demonstrated that functionalizing AgNPs with PVP enhances their physical and chemical stability under various ionic conditions and during interactions with target molecules, such as oligonucleotides and acpcPNA probes. This stability allows the nanoparticles to specifically interact and aggregate in response to the presence or absence of target DNA, resulting in a measurable color change on the paper-based sensor. A study conducted by Yusnaidar et al. [31] demonstrated the functionalization of silver nanoparticles (AgNPs) using citrate for the detection of creatinine. The citrate-functionalized AgNPs exhibited high sensitivity to creatinine, as evidenced by a distinct color change from yellow to dark black. This colorimetric response enables simple, rapid detection of creatinine levels, highlighting the potential of citrate-capped AgNPs as effective biosensors for clinical diagnostics.

3.2.2. Aptamer-based Functionalization

AgNPs have shown promise for the identification of the SARS-CoV-2 nucleocapsid protein via aptamer-based functionalization [36]. Detection limits as low as one ng/mL were achieved in both buffer solutions and human blood by optimizing aptamer concentration, incubation time, and surface passivation with cysteamine, thereby improving the stability and specificity of the BioSERS sensing device. This approach underscores the need to adjust biomolecule conjugation parameters to improve viral protein detection efficiency.

Specifically with reference to carcinoembryonic antigen (CEA) [36] AgNPs were functionalized with streptavidin to exploit the strong biotin-streptavidin interaction with biotinylated monoclonal antibodies for cancer biomarker detection. Using nanohybrid materials including gold nanoparticles and thiolate graphene oxide, this functionalization greatly enhanced electrochemical signals, enabling ultrasensitive detection down to 75 fg/mL in blood samples. The method emphasizes improving immunosensor performance by selectively conjugating antibodies to conductive nanomaterials.

3.2.3. Core–Shell Structures for Metal-Enhanced Fluorescence (MEF)

AgNPs coated with inert shells (e.g., silica or polymers) enable precise control of the distance between the nanoparticle and fluorophores. This architecture enhances quantum yield and photostability while mitigating photobleaching, making them ideal for ultrasensitive MEF biosensors. AgNPs may also be used as a colloidal label with an innocuous organic or inorganic shell, albeit [37]. This core-shell structure ensures a precise distance between the metal surface and the fluorescent dye and simultaneously enhances stability, biocompatibility, and dispersion [38].

3.2.4. Aggregation-Based Colorimetric Sensors

AgNPs functionalized with ligands that bind specific analytes can induce controlled aggregation, leading to surface plasmon resonance (SPR) shifts that appear as color changes. This is widely adopted in POC devices for its simplicity and low cost. Nonetheless, the assay must be carefully optimized to avoid false positives due to ionic strength or matrix effects. Thiol derivatives, such as 11-mercaptoundecanoic acid (11-MUA), can add carboxylic groups to nanoparticle surfaces, serving as anchor sites for subsequent bioconjugation [39]. Additionally, it is used to improve colloidal stability and provide reactive sites for functional group attachment) [40] and natural biopolymers like chitosan [41]. Another method is provided by dendritic polymers, which enable dense surface modifications and multivalent interactions with

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specific biomarkers. Beyond these, direct conjugation with antibodies and aptamers.[42], or peptides [43] allows AgNPs to act as targeted biosensing platforms for many clinical applications. AgNPs conjugated to glucose oxidase have been incorporated into electrochemical biosensors for the diagnosis of metabolic disorders, particularly diabetes, enabling accurate glucose level monitoring [44].

3.2.5. Nanocomposites for Enhanced Performance

AgNPs are integrated with supporting materials such as carbon nanotubes, graphene oxide [44]. Electrospun nanofibers provide increased surface area, conductivity, and structural stability. This combination enables robust biosensing platforms, particularly for electrochemical and hybrid optical devices.

4. Result and Discussion

4.1. Characterization of Silver Nanoparticles for Biosensor Applications

To effectively utilize silver nanoparticles (AgNPs) in biosensor applications, a comprehensive understanding of their characterization is essential, as it directly correlates with sensing performance. UV-Vis spectroscopy is widely employed to determine the optical properties and stability of AgNPs, with absorption peaks typically observed between 410 and 440 nm, which reflect particle presence and size distribution and are essential for optical sensing capabilities [45], [46], [47]. Complementary to this, dynamic light scattering (DLS) provides accurate measurements of particle size distribution and ensures uniformity in size, which is critical for consistent biosensor performance [48]. Morphological features such as particle shape and precise dimensions can be confirmed using transmission electron microscopy (TEM) [49], while scanning electron microscopy (SEM) offers additional information on surface morphology, both of which strongly influence the surface area and reactivity of AgNPs in biosensors [50].

Furthermore, X-ray diffraction (XRD) analysis determines the crystalline structure of AgNPs and confirms their purity, properties essential to stability and functionality in sensing platforms. Fourier transform infrared spectroscopy (FTIR) complements these techniques by identifying chemical compositions and functional groups, ensuring the presence of active moieties capable of interacting with target analytes. Together, these characterization approaches validate key physicochemical parameters, such as particle size and shape. Smaller nanoparticles (10–30 nm) with controlled morphologies—particularly spherical or plate-like—offer higher surface area and better analyte interaction, thereby enhancing sensitivity and specificity. Reported surface areas in the range of 32–48 m^2/g further support the abundance of active sites, directly improving detection capabilities[51]. Stable plasmon resonance values of 2.82–3.24 eV are equally crucial for optical biosensors, as they dictate the efficiency of signal transduction. In terms of composition, a high silver content (84–94%) has been consistently observed, ensuring desirable properties such as conductivity and reactivity. Finally, stability and biocompatibility assessments remain indispensable for the practical use of AgNPs in medical diagnostics, ensuring their safe and effective implementation in biosensor platforms.

Altogether, these characterization insights affirm that the structural, optical, and chemical attributes of AgNPs are directly tied to their role in enabling highly sensitive and specific biosensing systems [52].

4.2. Enhancing Sensitivity in Poc Diagnostics Using AgNPs

AgNPs are effective substrates for Surface-Enhanced Raman Spectroscopy (SERS) because they create strong electromagnetic hotspots that significantly improve Raman scattering signals of molecules adsorbed on their surfaces [53]. AgNPs' special surface plasmon resonance (SPR) effect, which enhances electromagnetic fields near the nanoparticle surface, primarily accounts for the increased sensitivity in diagnostic platforms that use them. In optical and electrochemical detection systems, this amplification enhances interaction with target analytes. Raising signal intensity [54]. Moreover, AgNPs offer a high surface-to-volume ratio, which facilitates a higher density of functionalization sites and improves capture efficiency for low-abundance biomarkers, as summarized in ***Table 1***.

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For neurodegenerative disease biomarkers, a SERS sensor based on AgNPs immobilized in chitosan films (AgNP/CS) demonstrated nanomolar limits of detection (LOD) for amyloid-β (Aβ42) aggregates using a 532 nm laser. Further optimization via laser-induced deposition (AgNP/LID) improved nanoparticle distribution and sensitivity, achieving a remarkable 3 pM LOD with a 633 nm laser. Notably, these substrates distinguished amyloid aggregates from monomers, underscoring SERS' capability for conformational differentiation [55].

In infectious disease diagnostics, a SERS substrate composed of uniformly distributed AgNPs on black phosphorus (BP) flakes enabled the detection of sepsis biomarkers interleukin-3 (IL-3) and procalcitonin (PCT) with LODs of 1000 fM and 100 fM, respectively. The platform's enhancement factor reached ~10^{14}, facilitating the identification of distinct Raman signatures from structurally similar protein biomarkers in complex samples [56].

Table 1. *Applications of Silver Nanoparticles (AgNPs) in Point-of-Care Diagnostic Sensors: Target Analytes, Sensor Types, Functionalization Strategies, Detection Mechanisms, Sensitivity Levels, and Selectivity*

Diagnostic Target	Type of Sensor	Functionalization of AgNPs	Detection Mechanism	LOD/ Sensitivity	Selectivity
Proline	Colorimetric	$CuSO_4$-modified paper biosensor	Color change	LOD : 4.34 mM	High
HPV-16 E7	Dielectrode sensor	AgNP-conjugated capture probe	Plasmon resonance	LOD: 10–100 aM	High [62]
Ascorbic Acid (AA)	Optical sensor	AgNPs coating, enzyme coating	Optical response	Sensitivity: 0.013 nm/µM	High [63]
Squamous Cell Carcinoma Antigens (SCCA)	Electrochemical immunosensor	Ag@APTES-GS, Ag@KIT-6	Signal amplification	LOD: 17 fg/mL	High [64]
Dopamine (DA)	Electrochemical sensor	Ag@CQDs–rGO nanocomposite	Redox reaction	LOD: 1.59 nM	High [65]
Glucose	Electrochemical	Not specified	Electrochemical response	Not specified	High [66]
Cancer	Optical	Surface modification	Accumulation in tumor tissues	Not specified	High [67]

4.3. Improving Selectivity Through Functionalization of AgNPs

High selectivity achieved through AgNPs functionalization directly translates to improved diagnostic accuracy by reducing false positives and negatives. Enhanced selectivity ensures that the biosensor preferentially binds the intended target amidst a plethora of potentially interfering substances in biological samples such as blood, saliva, or urine [57]. This precise targeting not only increases the reliability of diagnostic results but also enables lower limits of detection and quantification, which are essential for early disease diagnosis and monitoring.

AgNPs functionalization typically involves conjugation with biomolecules such as antibodies, aptamers, and small-molecule ligands, each offering unique advantages for target specificity. Antibodies bind antigens with high affinity, making them ideal for detecting protein biomarkers in immunosensors. Aptamers—short, synthetic oligonucleotides selected for their strong binding affinity—offer chemical stability and ease of modification, making them suitable for diverse targets, including proteins and small molecules [58]. Ligands, such as peptides or receptor analogs, afford tailored interactions with specific cellular receptors or analytes [59]. Conjugation methods include covalent bonding via thiol or amine groups, electrostatic adsorption, and click chemistry, ensuring stable and oriented immobilization of these recognition elements on AgNPs surfaces.

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High selectivity directly enhances diagnostic accuracy by reducing nonspecific interactions that can obscure or mimic accurate target signals. This is critical in biological samples where abundant proteins, salts, and other biomolecules may interfere with sensor responses. Table 1 illustrates how functionalization strategies, such as enzyme coating, aptamer conjugation, and ligand binding, have been applied to different diagnostic targets to enhance selectivity and sensitivity. Functionalized AgNPs facilitate preferential binding of target analytes, improving signal-to-noise ratios and lowering detection limits. Kirbay et al. developed an electrochemical immunosensor for D-dimer detection by electrodepositing lactose methoxide aniline-functionalized AgNPs (LMA-AgNPs) onto a screen-printed carbon electrode. The functionalization with lactose methoxide aniline not only provided a stable nanostructured platform but also facilitated the immobilization of specific anti-D-dimer antibodies. This configuration enabled highly selective antigen-antibody interactions, evidenced by negligible interference from substances such as urea, insulin, C-reactive protein, and serum amyloid A. The sensor demonstrated a wide linear detection range and ultra-low limit of detection (0.2 fg/mL), illustrating that targeted surface chemistry and antibody immobilization are key to enhancing selectivity [60].

In another study, Ortega et al. reported a microfluidic immunosensor that utilizes chitosan-coated AgNPs (AgNPs-Cts) covalently attached within the sensing channel for the detection of epithelial cell adhesion molecules (EpCAM). The biocompatible chitosan layer provided an effective scaffold for covalent immobilization of monoclonal anti-EpCAM antibodies, ensuring high specificity toward the biomarker in peripheral blood samples. This approach enabled a sensitive and reproducible assay with superior performance compared to commercial ELISA. The covalent attachment and antifouling properties of chitosan significantly reduced nonspecific binding and improved selectivity in a complex biological matrix [61].

Collectively, these studies emphasize that selectivity enhancement in AgNP-based medical sensors hinges on deliberate surface functionalization strategies—such as specific ligand conjugation and use of biocompatible coatings—that promote targeted biomarker capture while minimizing interference. Covalent immobilization and antifouling layers are effective in maintaining sensor specificity and reliability in clinical settings. Table 1 further supports this by highlighting diverse examples of functionalized AgNP-based biosensors for diagnostic targets.

In conclusion, the functionalization of AgNPs with carefully selected and stably immobilized recognition elements is vital for improving selectivity and diagnostic accuracy. Addressing challenges posed by complex biological environments through antifouling strategies and sample preparation enhances the clinical applicability of AgNPs-based diagnostic platforms.

4.4. Current Challenges and Future Perspectives in Silver Nanoparticle-Based Diagnostics

The application of silver nanoparticles (AgNPs) in diagnostic devices offers significant advantages in sensitivity, selectivity, and rapid detection. Despite these benefits, several challenges remain before their widespread commercial adoption can be realized, particularly concerning the scalability of production and seamless integration into reliable, user-friendly diagnostic platforms.

Scaling up the synthesis of AgNPs from laboratory to industrial scale presents numerous challenges. Maintaining consistent nanoparticle size distribution, morphology, and surface chemistry at large volumes is critical for reproducible sensor performance. Variations during scale-up can affect the optical and electrical properties that are fundamental to diagnostic sensitivity. Moreover, cost-effective, environmentally friendly synthesis routes that minimize the use of hazardous reagents and waste are urgently needed to meet regulatory standards and sustainability goals.

Integration of AgNPs into commercial diagnostic devices also requires compatibility with manufacturing processes, including microfabrication, printing technologies, and flexible substrates. The immobilization of AgNPs must ensure strong adhesion, stability, and preservation of functional properties under varied storage and operating conditions.

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Developing standardized protocols for quality control and device validation remains a critical priority to ensure regulatory compliance and user safety.

Recent innovations focus on multifunctional AgNPs-based platforms capable of multiplexed biomarker detection and theranostic applications combining diagnosis and treatment. Hybrid nanomaterials, in which AgNPs are coupled with graphene, quantum dots, or magnetic nanoparticles, show promise for enhancing signal amplification and broadening diagnostic capabilities. Advances in machine learning and data analytics integrated with AgNPs-based biosensors are improving the interpretation of complex signals, enabling personalized and predictive diagnostics.

Furthermore, the miniaturization and integration of AgNPs sensors with smartphone-based platforms and wearable technologies are transforming point-of-care testing into continuous health-monitoring systems. Research is also expanding into greener synthesis approaches using biological agents such as plant extracts and microorganisms, which offer environmentally benign alternatives. Future studies are expected to delve deeper into the mechanistic understanding of AgNPs-biomolecule interactions to fine-tune selectivity and stability further.

In conclusion, overcoming challenges related to scalable production and commercial device integration, combined with rapid technological innovations, will define the future trajectory of AgNPs-based diagnostics. Interdisciplinary collaboration spanning nanotechnology, materials science, engineering, and clinical research is essential to harness the full potential of AgNPs in next-generation diagnostic solutions.

5. Conclusion

Silver nanoparticles (AgNPs) have demonstrated remarkable potential to revolutionize point-of-care (POC) medical diagnostics through their unique physicochemical properties, which significantly enhance sensor sensitivity, selectivity, and stability. Their surface plasmon resonance (SPR) effect enables substantial signal amplification in optical and electrochemical biosensors, while versatile surface functionalization techniques provide high specificity toward diverse disease biomarkers. Despite these advances, challenges such as nanoparticle aggregation, oxidation, biocompatibility, and manufacturing scalability remain critical barriers to widespread clinical adoption. Addressing these challenges through innovative synthesis methods, robust surface coatings, and integration with emerging technologies, such as microfluidics, wearable devices, and data analytics, will be vital to realize the clinical and commercial potential of AgNPs-based diagnostics fully. Future research focusing on environmentally friendly production, enhanced stability, and mechanistic understanding of AgNPs-biomolecule interactions will further optimize sensor performance. Ultimately, multidisciplinary collaboration across nanotechnology, materials science, and clinical disciplines will accelerate the translation of AgNPs-enabled diagnostic platforms, paving the way for rapid, reliable, and personalized healthcare solutions worldwide.

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