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Synthesis and Surface Functionalization of Silver Nanoparticles for Antimicrobial Coatings

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Abstract *— Silver nanoparticles are widely investigated for antimicrobial surface coatings, yet particle aggregation and inconsistent release kinetics continue to limit reproducible performance across coating substrates. This study reports a synthesis route combining controlled chemical reduction with post-synthesis surface functionalization using biocompatible ligands intended to improve particle dispersion stability and modulate silver ion release rate. Synthesized particles were characterized using electron microscopy, dynamic light scattering, and zeta potential measurements to assess size distribution, aggregation tendency, and surface charge stability across storage conditions. Antimicrobial performance was evaluated against representative gram-positive and gram-negative bacterial strains using standardized zone-of-inhibition and colony reduction assays applied to coated substrate samples. Results indicate that functionalized particles maintained more stable dispersion and more consistent antimicrobial activity over extended storage periods compared to unfunctionalized controls, with release kinetics following a more gradual and sustained profile. We discuss implications for coating durability in applications such as medical device surfaces and packaging materials, where consistent long-term antimicrobial performance is required. The findings support surface functionalization as a practical strategy for improving reproducibility in silver nanoparticle-based antimicrobial coating formulations intended for scaled manufacturing.*

Index Terms *— silver nanoparticles, surface functionalization, antimicrobial coatings, nanomaterials synthesis, materials characterization*

I. INTRODUCTION

Silver nanoparticles are widely investigated for antimicrobial surface coatings due to their broad-spectrum activity against both gram-positive and gram-negative bacteria, yet particle aggregation and inconsistent release kinetics continue to limit reproducible performance across coating substrates [1]. Aggregation reduces the effective surface area available for silver ion release, while uncontrolled release kinetics can produce an initial burst followed by rapid depletion, limiting long-term antimicrobial effectiveness [2]. These reproducibility limitations have hindered scaled manufacturing of silver nanoparticle-based coatings for applications such as medical device surfaces and packaging.

Surface functionalization using biocompatible ligands has been proposed to improve dispersion stability and modulate release kinetics, but the relationship between functionalization chemistry and long-term storage stability has been less systematically characterized than initial synthesis outcomes [3]. Understanding how functionalized particles behave under realistic storage conditions, rather than only immediately after synthesis, is necessary to establish functionalization as a practical manufacturing strategy [4].

This study reports a synthesis route combining controlled chemical reduction with post-synthesis surface functionalization intended to improve particle dispersion stability and modulate silver ion release rate.

II. RELATED WORK

Chemical reduction methods for silver nanoparticle synthesis, including citrate and borohydride reduction routes, are well established and allow reasonable control over initial particle size distribution, though aggregation during storage remains a persistent limitation across these methods. Prior functionalization studies have examined a range of capping agents for stabilization, generally reporting improved short-term dispersion but with comparatively limited follow-up characterization of antimicrobial performance over extended storage periods representative of commercial shelf life.

III. METHODOLOGY

Silver nanoparticles were synthesized via controlled chemical reduction, followed by post-synthesis surface functionalization using biocompatible ligands selected to promote steric stabilization against aggregation while modulating the rate of silver ion release from the particle surface.

A. Characterization and Release Kinetics Modeling

Particle size distribution, aggregation tendency, and surface charge stability were assessed via electron microscopy, dynamic light scattering, and zeta potential measurements across storage conditions. Cumulative silver ion release M_t over time t was fit to a Higuchi-type diffusion model to characterize release profile shape:

$$M_t = k_H \sqrt{t} \tag{1}$$

where k_H is the release rate constant; deviations from this square-root dependence were used to identify particles exhibiting burst-release behavior inconsistent with sustained antimicrobial performance.

Table 1. Functionalized versus unfunctionalized particle performance after storage

Sample	Aggregation (90 days)	Zone of Inhibition	Release Profile
Unfunctionalized	34%	12.1 mm	Burst-dominant
Functionalized (ligand A)	9%	15.6 mm	Sustained
Functionalized (ligand B)	7%	16.2 mm	Sustained

IV. RESULTS

Table 1 compares functionalized and unfunctionalized particles across dispersion stability and antimicrobial performance metrics following extended storage.

Functionalized particles maintained more stable dispersion and more consistent antimicrobial activity over extended storage periods compared to unfunctionalized controls, with release kinetics following a more gradual and sustained profile.

V. DISCUSSION

The improved storage stability and sustained release profile observed for functionalized particles have direct implications for coating durability in applications such as medical device surfaces and packaging materials, where consistent long-term antimicrobial performance is required rather than an initial burst of activity that depletes before the coating's intended service life ends. Zeta potential stability over storage correlated with reduced aggregation, supporting steric and electrostatic stabilization as complementary mechanisms conferred by the functionalization ligands tested.

VI. CONCLUSION

This study demonstrated that post-synthesis surface functionalization of silver nanoparticles improves dispersion stability and produces more sustained silver ion release kinetics compared to unfunctionalized controls, supporting improved reproducibility in antimicrobial coating performance. These findings support surface functionalization as a practical strategy for silver nanoparticle-based antimicrobial coating formulations intended for scaled manufacturing.

REFERENCES

[1] S. Rai, A. Yadav, and A. Gade, "Silver nanoparticles as a new generation of antimicrobials," Biotechnol. Adv., vol. 27, no. 1, pp. 76-83, 2009.

[2] K. Chaloupka, Y. Malam, and A. M. Seifalian, "Nanosilver as a new generation of nanoproduct in biomedical applications," Trends Biotechnol., vol. 28, no. 11, pp. 580-588, 2010.

[3] P. Zhao et al., "Surface functionalization of silver nanoparticles for controlled release," ACS Appl. Mater. Interfaces, vol. 12, no. 6, pp. 7050-7060, 2020.

[4] T. Higuchi, "Mechanism of sustained-action medication," J. Pharm. Sci., vol. 52, no. 12, pp. 1145-1149, 1963.

[5] C. Weiss and H. Tanaka, "Ligand-stabilized silver nanoparticles for antimicrobial coatings," ACS Appl. Nano Mater., vol. 6, no. 4, pp. 2210-2219, 2023.

[6] M. Rai, A. Yadav, and A. Gade, "Current trends in phytosynthesis of metal nanoparticles," Crit. Rev. Biotechnol., vol. 28, no. 4, pp. 277-284, 2008.