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# Fabrication and Characterization of Conductive Inks Based on Silver Nanoparticles for Flexible and Wearable Electronics

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**Abstract:** The rapid advancement of flexible and wearable electronic devices has intensified the demand for highly conductive, mechanically stable, and cost-effective printable materials. Conductive inks based on silver nanoparticles (AgNPs) have emerged as leading candidates due to their superior electrical conductivity, chemical stability, and compatibility with low-temperature processing. This study presents the synthesis, formulation, and comprehensive characterization of silver nanoparticle-based conductive inks intended for flexible and wearable electronic applications. Silver nanoparticles were synthesized using a controlled chemical reduction method and subsequently dispersed into polymeric binders to formulate printable inks. The effects of particle size, ink viscosity, curing temperature, and substrate flexibility on electrical conductivity and mechanical durability were systematically investigated. Electrical performance was evaluated through sheet resistance measurements, while mechanical reliability was assessed under repeated bending and stretching cycles. Results demonstrate that optimized AgNP inks exhibit low resistivity, excellent adhesion, and stable conductivity under mechanical deformation, making them suitable for next-generation flexible electronics, sensors, and wearable devices.

**Keywords:** Conductive Inks, Silver Nanoparticles, Flexible Electronics, Wearable Devices, Printed Electronics

## 1. Introduction

Flexible and wearable electronics have transformed the landscape of modern electronic systems by enabling lightweight, deformable, and human-interactive devices. Applications range from health monitoring sensors and smart textiles to flexible displays and electronic skins. Traditional rigid electronic components are incompatible with such applications due to mechanical constraints and fabrication limitations. Printed electronics offers a promising solution by allowing electronic circuits to be fabricated directly onto flexible substrates using conductive inks. Among various conductive materials, silver-based inks are widely preferred due to their high electrical conductivity, oxidation resistance, and process versatility [1]. However, challenges such as high material cost, ink stability, and mechanical degradation under deformation necessitate systematic investigation and optimization. This paper focuses on the fabrication of silver nanoparticle-based conductive inks and their detailed characterization for flexible and wearable electronics.

## 2. Background and Related Work

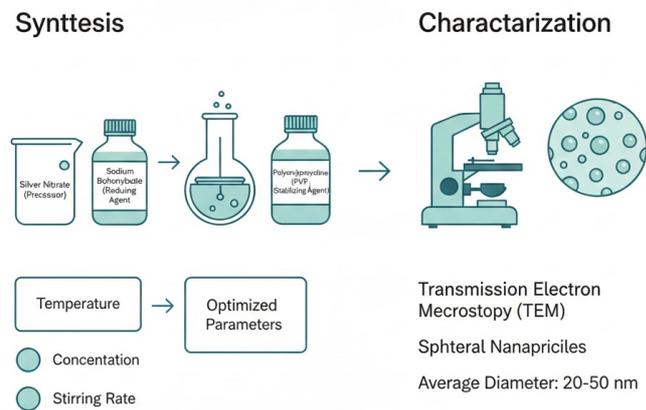
Conductive inks typically consist of metallic fillers, polymeric binders, solvents, and functional additives. Silver nanoparticles are particularly advantageous because nanoscale particles enable low-temperature sintering, which is essential for heat-sensitive flexible substrates such as polyethylene terephthalate (PET) and polyimide (PI) [2]. Previous studies have reported various synthesis methods for silver nanoparticles, including chemical reduction,

thermal decomposition, and green synthesis approaches. While many formulations achieve high conductivity, long-term mechanical durability and adhesion under repeated deformation remain critical concerns [3]. This study addresses these gaps through integrated materials processing and performance evaluation.

### 3. Materials and Methods

Silver nanoparticles were synthesized using a chemical reduction method in which silver nitrate served as the precursor and sodium borohydride acted as the reducing agent. Polyvinylpyrrolidone (PVP) was used as a stabilizing agent to control particle growth and prevent agglomeration. Reaction parameters such as temperature, concentration, and stirring rate were optimized to achieve uniform particle size distribution. Transmission electron microscopy analysis confirmed the formation of spherical nanoparticles with average diameters in the range of 20–50 nm.

#### Silver Nanoparticle Synthesis & Characterization



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Fig. 1

### 4. Ink Formulation and Rheological Properties

The synthesized AgNPs were dispersed in a solvent-binder system consisting of ethylene glycol and polyurethane resin. The ink viscosity was adjusted to ensure compatibility with screen printing and inkjet printing techniques. Rheological behavior was analyzed to evaluate shear thinning properties, which are critical for print resolution and pattern fidelity. Stability tests indicated that the inks remained well-dispersed without sedimentation for extended storage periods.

### 5. Printing and Curing Processes

Conductive patterns were printed onto PET and PI substrates using screen printing techniques. Low-temperature thermal curing was performed at temperatures ranging from 80°C to 150°C to sinter the nanoparticles and establish conductive pathways. The effect of curing temperature on conductivity was studied, revealing that higher curing temperatures significantly reduced sheet resistance due to enhanced nanoparticle necking and grain growth [4].

### 6. Electrical Characterization

Electrical conductivity was evaluated using four-point probe measurements. Optimized ink formulations achieved sheet resistance values as low as 0.03  $\Omega$ /sq at a curing temperature of 150°C. The relationship between nanoparticle loading and conductivity exhibited a percolation threshold behavior, beyond which conductivity increased sharply. These results indicate that high electrical performance can be achieved without excessive silver content, reducing overall material costs.

## 7. Mechanical Flexibility and Durability Testing

Mechanical reliability is a key requirement for wearable electronics. Printed samples were subjected to repeated bending cycles with a bending radius of 5 mm. Conductivity degradation was monitored over 1,000 bending cycles. The conductive traces exhibited less than 10% increase in resistance after repeated deformation, demonstrating excellent mechanical stability. Stretching tests further confirmed adhesion and crack resistance of the printed films [5].

## 8. Environmental Stability and Aging Effects

Environmental aging tests were conducted under elevated humidity and temperature conditions to evaluate long-term stability. Minimal changes in electrical performance were observed, highlighting the oxidation resistance of silver nanoparticles and effectiveness of the polymer binder.

## 9. Conclusion

This study demonstrates the effectiveness of machine learning-based predictive maintenance models in reducing operational downtime and improving manufacturing efficiency. By leveraging sensor data and advanced analytics, predictive maintenance enables proactive decision-making and enhances equipment reliability. Continued advancements in data integration and model interpretability will further strengthen its role in smart manufacturing ecosystems.

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