# Preparation and Characterization of Conductive Ink for Printed Electronics

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***Abstract*—Silver precursor ink was synthesized by a simple and environmental friendly method based on chemical reduction. The stability, particle size, viscosity and surface tension of the ink was adjusted by adding polymeric capping agent. Silver nanoparticles were characterized using scanning electron microscopy (SEM) and thermo gravimetric analysis (TGA). The silver pattern fabricated on the glass substrate was characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM) and electrical measurements. A specific interest about the size distribution and electrical conductivity at room temperature were considered. The low resistivity of silver patterns suggested applications for ink-jet printing of electronics devices.**

***Keywords*—Silver solution ink, Silver nanoparticle ink, Conductive ink**

## I. Introduction

Over a past decade, the electronics has seen a dramatic reduction in the size especially in integrated circuits. The industry is going towards size reduction along with fast and inexpensive processes. The so-called “smart materials” have become a very attractive and actively developing area of research in the last few years [1-10] not only because of their intellectual beauty, but also due to real possibility of the devices which adapt to the varying chemical and physical conditions in the environment [5, 6]. Traditional methods for fabrication of circuit patterns (screen printing, photolithography and electroplating) make use of selective masking and etching technologies to create regions of metallization on non-conducting substrates [11]. Such methods though effective, have the disadvantages of material wastage, chemical pollution or slow product translation. Hence, the researchers are now interested in direct writing technologies where the material having desirable electronic properties is deposited over a substrate in particulate form and then converted into conductive elements.

Recently, conductive inks were synthesized using different metal precursors like carbon, silver, copper etc. and their properties were studied. The characteristics which were analyzed include resistivity, viscosity, stability and cost. One of the major challenges along with cost was the manufacturing technique. Along with it the ink has enough adhesion with the substrate. Metals nanoparticles, capping agents, reducing agents and temperature were studied for the formulation of conductive inks. However, several specific characteristics of metallic nanoparticles, such as enhanced reactivity of surface atoms, decrease in melting point with size, and high electric conductivity make them very attractive for the fabrication of electronic devices.

Due to their high electrical conductivity, inks based on silver nanoparticles are excellent candidates for printable electronics. However, most commercially available inks use either high boiling point solvents or toxic chemicals which cause problems in real industrial applications [12, 14].

In this work, we report the synthesis of a stable silver precursor ink by a simple, cost effective and environmentally friendly method. Patterns of conductive ink drawn over glass substrate were subjected to thermal treatments at different temperatures for various times. The sintered films showed good conductivities demonstrating that the inks are suitable for printing electronic circuitry on thermally sensitive substrates.

## II. Experimental details

### A. Materials

The reagents include metal precursor (silver), water, polymeric capping agent, reducing agent, alcohol and polymeric viscosifying solution.

### B. The preparation of silver precursor ink and silver conductive patterns

Silver nanoparticles were produced by mixing stoichiometric amount of capping agent and water with reducing agent followed by stirring for 2 hours. Metal precursor in solution was injected and stirred for 24 hours. Initially the colour of the solution was transparent gradually it became dark blackish.

The solution was sonicated at 65$^{o}$C for 2 hours and after cooling it was titrated with the addition of 150 ml of ethanol. and then decanted. After decanting the supernatant, the precipitate was centrifuged at 6,000 rpm for 30 min to further concentrate the sample.

Then the sample was again dispersed in water and homogenized at room temperature. The resulting solution was again centrifuged at 4,000 rpm for 20 min. to remove excess capping agent. This washing step was performed 3-4 times.

The removal of capping content was determined by thermo gravimetric analysis (TGA) before and after washing. Viscosifying solution was added in the ink and patterned over the substrate.

### *C. Heat treatment of silver patterns*

The sample was allowed to dry in air for 20 min. After that the samples were sintered at different temperatures in the range from 50 to 500°C [15]. The colour of the samples changed from black to creamy when it was heated.

### *D. Characterization*

Thermo gravimetric analysis (TGA) of the precipitate of the capped particles with alcohol and after washing steps, where the capping agent was completely removed after the washing sequence was completed.

The surface morphology of the samples was observed by FESEM.

Fourier Transformed Infrared Spectrometry (FTIR) was done for the observation of compositional analysis.

## III. Results and Discussion

### *E. FTIR Spectroscopy*

| Wavelength ($cm^{-1}$) | Bond Vibration Absorption |
|---|---|
| 1654 | C=O |
| 1078 | C—N |
| 1020 | C—N |

**Table.1** The bond vibrations along with wavelength.

The nano-silver ink FTIR spectra values derived from the graph mentioned in Table 1 depict that the C=O and C–N bond vibration absorption generated at the wavelength of about 1654$cm^{-1}$, as well as 1078 and 1020$cm^{-1}$, respectively, even though the latter is very slightly[16-18].

### *F. The physical properties of silver precursor ink*

To make conductive ink, the properties of this ink, including its stability, particle size, viscosity and surface tension must be formulated to fit the physical and rheological requirements of fluid flow during patterning. The stability of the silver precursor ink is a key factor in applications of printing conductive patterns. Therefore, to prevent the rapid precipitation of Ag, a viscosifying solution was added.

### *G. Morphology and microstructure of the silver patterns*

The silver precursor ink was used to prepare electrically conductive thin patterns. With heat treatment the film changed colour from dark greyish to creamy. The silver film was well adhered to the substrate without cracks (Fig. 1) after sintering and the nonconductive film became conductive [19, 20].

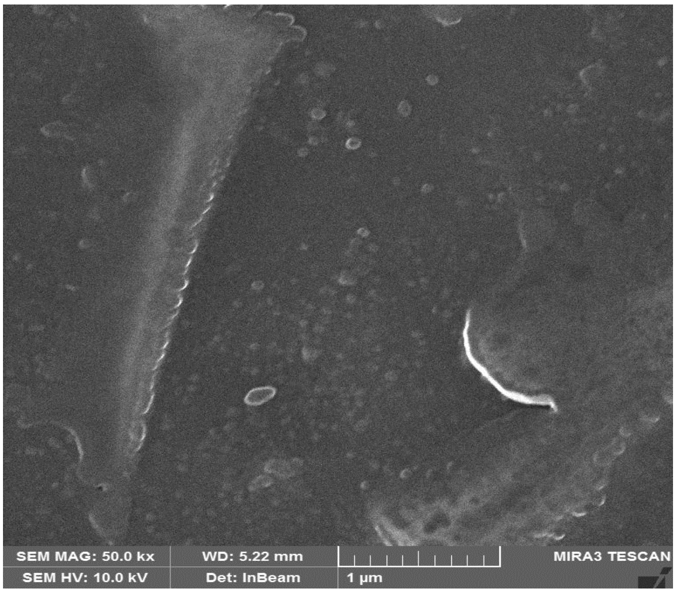


**Figure 1**
FE-SEM image of silver nanoparticles tested after forming a suspension of silver nanoparticles powder.

### *H. Electronic properties of the silver patterns*

The sintering temperature is an important factor that influences the resistivity of the silver conductive pattern [21-23].

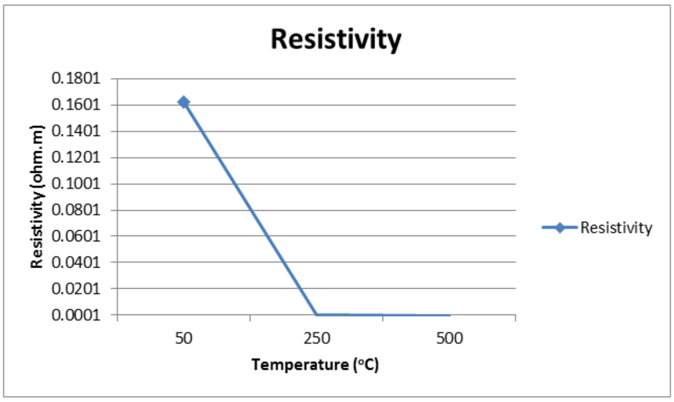


**Figure 2** The resistivity change of the silver pattern as a function of the sintering temperatures.

## IV. Conclusions

The described conductive ink can be used to produce flexible electrical circuits via simple pattering techniques. Highly dispersed Ag nanoparticles were synthesized for printed electronics and a facile approach was designed to make silver conductive ink. Cost effectiveness of the ink was controlled while allowing its patterning on various substrates like glass or flexible films depending upon the viscosifying solution. The conductivity was enhanced with rise in temperature and was efficient for ambient temperature conditions.

Among the uses of this ink include pressure sensors, level sensors, digital adjustments for electronic circuits, oil pressure sensors in automobiles, glucose biosensors and MEMS (Micro Electro Mechanical Systems), which illustrate the wide variety of applications.

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