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Low temperature sintering nano-silver conductive ink printed on cotton fabric as printed electronics

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ABSTRACT

Monodisperse silver nanoparticles conductive ink was successfully synthesized by in-situ synthesis method in an aqueous solution. The size distribution of the Ag nanoparticles was tested and the average diameter was within 10 nm. A spontaneous coalescence and sintering of Ag NPs at 60 °C for 30 min was realized in the presence of hydrogen chloride. The interface bonding between dispersant and silver nanoparticles was investigated by XRD and FTIR. The conductive ink doped with polyaniline has a good adhesion to cotton surface and better conductivity. The highest conductivity was $2 \times 10^{-5}\,\Omega\,m$ when the silver content was 30 wt.%. This prepared conductive ink could be printed on cotton fabric to form conductive circuits and the conductivity can remain at least 30 days. These promising results suggest applications of printed electronics devices using textiles as substrates.

1. Introduction

Recently, printed electronics has attracted considerable research interest due to its potential of development for flexible display, antennas, sensors and wearable electronics [1–3].

Functional inks are main barrier for the application of printed electronics due to their high cost, instability and high sintering temperature. So far, many conductive materials have been used as conductive ink, such as conductive polymers [4], carbon [5], graphene [6], organo-metallic compounds [7], metal precursors [8] and metal nanoparticle (NPs) [9]. Among them, conductive polymers, carbon, grapheme have poorer conductivity ($10–10^2\,S\,cm^{-1}$) compared with metal ($10^4–10^5\,S\,cm^{-1}$). In addition, organo-metallic compounds and metal precursors are required to disperse in hazardous organic solvents like toluene, xylene and alkane and sinter with heat treatment (>250 °C) to achieve coalescence [10–13]. This heat treatment, that is sintering, is an important step in printing of metal nanoparticle inks to remove dispersant and auxiliaries, which will seriously affected the nature of textiles of fabrics as high temperature leading to deformation, hardened hand feel and yellowing, especially those thermal sensitive fibers. Furthermore, high temperature also causes oxidation of some metallic nanostructures and results in poor conductivity.

There were some approaches to offer alternative sintering techniques, such as laser, microwave or DC sintering techniques, instead of heating [14,15]. These techniques are capable of sintering at a relatively low processing temperature but more or less unavoidably involve problems like expensive equipment, complex procedures and not easily large-scale production. Some researchers have demonstrated that sintering could be realized at room temperature in the presence of so-called sintering agent [16,17], such as NaCl [18]. But optimization of the lattice structure of silver NPs during the sintering process can't be achieved, which would decrease the compactness of the printed conductive pattern and affect conductivity [18].

To the best of our knowledge, there are few studies reporting on this work, especially using natural textiles as flexible substrates. Moreover, cellulose had been identified as a smart material for its piezoelectric property [19], Jaehwan Kin [20] reported the conductive ink printing on cellulose film, but the sintering temperature was 200 °C and cellulose will be damaged. Using textiles as substrate, one challenge is low sintering temperature and mild process condition. Herein, we proposed a facile, environmental friendly

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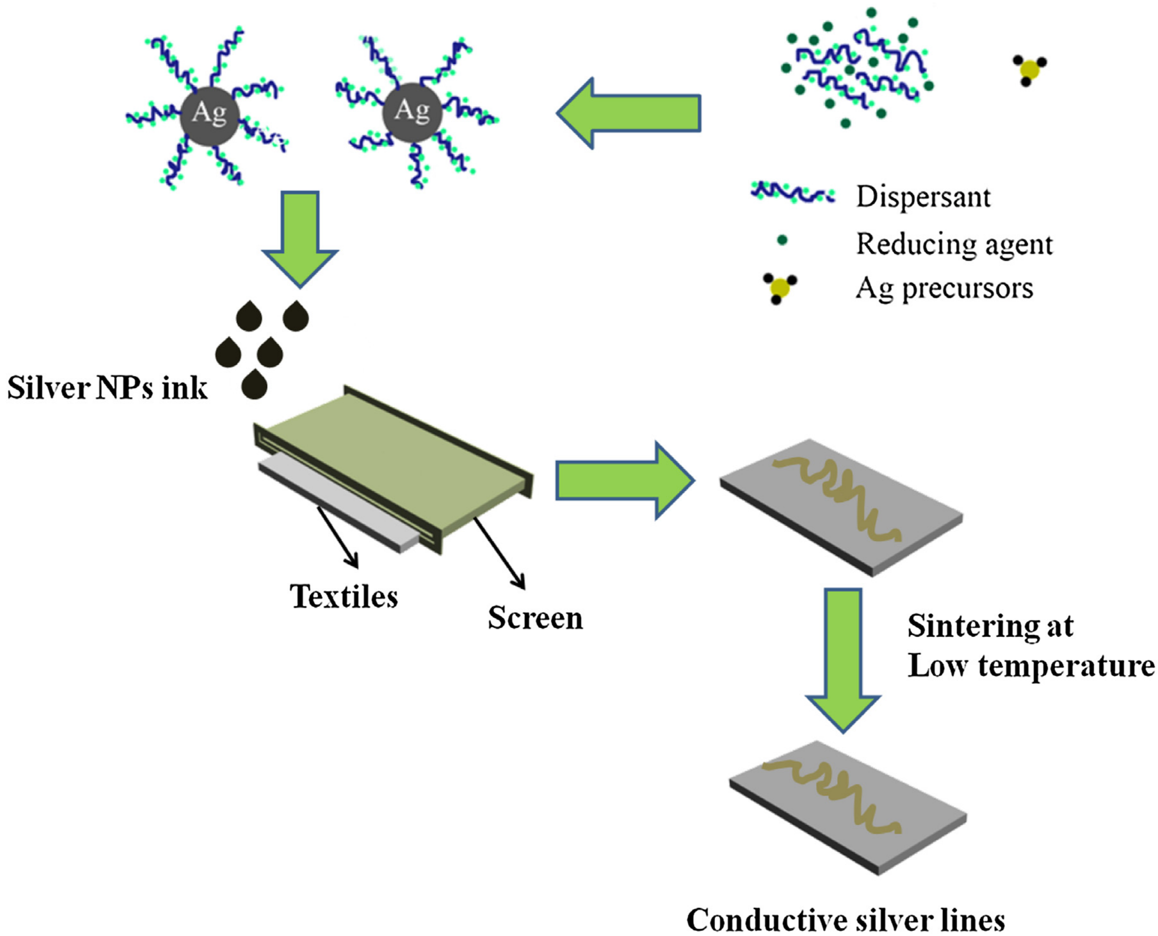

Fig. 1. The preparation of nano-silver conductive ink and its application on cotton fabric.

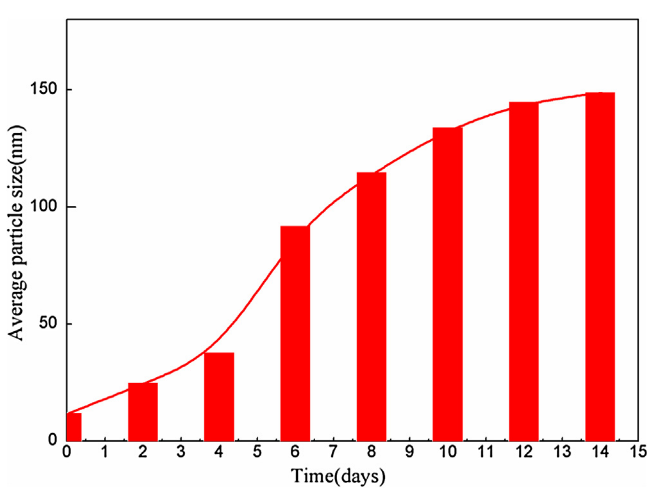

Fig. 2. The average particle size of nano silver ink over times.

and low cost method to prepare nano-silver conductive ink and successfully printed it on cotton fabric which could sintering spontaneously at low temperature. The related process was displayed in Fig. 1. The impact of sintering agent and the additives on the conductivity of this ink was investigated and the morphology of sintered silver NPs as well as its' conductivity were also characterized and measured.

2. Experiment details

2.1. Materials

All of the chemical reagents used in the experiments were analytical grade and used as raw materials without further purification. Silver nitrate ($AgNO_3$, 99.8%, Shanghai Shenbo Chemical Co., Ltd, China), Iron (II) sulfate heptahydrate ($FeSO_4{\cdot}7H_2O$, 99%), trisodium citrate dihydrate ($Na_3C_6H_5O_7{\cdot}2H_2O$, 99%), sodium nitrate ($NaNO_3$, 99%), enthanol ($C_2H_5OH$, 99.7%), glycerol ($C_3H_8O_3$, 99%), glycol ($C_2H_6O_2$, 99%), aniline ($C_6H_7N$, 99.5%), ammonium persulphate ($(NH_4)_2S_2O_8$, 98%) and sulfuric acid (H_2SO_4, 98%) were purchased from Sinopharm Chemical Reagent Co., Ltd, China. Cotton fabric (124 g/m^2, Saintyear Holding Group Co., Ltd, China). A4 paper (YALONG paper products Co., Ltd, Kunshan, China). Transparent tape (19mm × 32.9m, 600#, 3 M materials technology Co., Ltd, Suzhou).

2.2. Synthesis of Ag NPs

The silver NPs was produced by in-situ synthesis and collected by centrifugal process. We improve the traditional Carey-Lea [21,22] synthesis method, 7.5 g $FeSO_4{\cdot}7H_2O$ and 14 g $Na_3C_6H_5O_7{\cdot}2H_2O$ were sequentially dissolved in 38.5 ml deionized water to form a uniform solution. Then 2.5 g $AgNO_3$ was dissolved in 22.5 ml deionized water and used as the metal precursors solution. The silver paste was synthesized by adding the above mixture into $AgNO_3$ solution drop by drop with continuous magnetic stir-