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Preparation of silver nanofluid by the submerged arc nanoparticle synthesis system (SANSS)

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Abstract

The purpose of this study is fabrication and characterization of silver nanofluid by the submerged arc nanoparticle synthesis system (SANSS). The silver metal electrodes under the electrical discharge will melt and evaporate rapidly and condense to form the nanoparticles in the lower temperature dielectric liquid and produce the suspended nanoparticle. The results showed that the spherical nanosilver particle formed in the ethylene glycol and the mean particle size is about 12.5 nm. The prepared silver nanofluid was irradiated under the 410 nm visible light, electrons could be excited from the valence band to the conduction band. The silver nanofluid more closely resembles Newtonian fluids.

Keywords: Nanostructured materials; Nanofabrications; X-ray diffraction; Photoelectron spectroscopies

1. Introduction

Pt, Pd, Au, and Ag noble metal nanoparticles have been studied because of their unique catalytic, electric, magnetic, optical and mechanical properties that are different from bulk materials [1–4]. Various approaches have been employed for the preparation of nanosized metal particles. Among the noble metal nanoparticles, silver nanoparticles have been widely studied. The processing of nanosized particles can be briefly classified into several regimes, solution phase method [5–8], laser ablation [3], sonochemical method [9,10], and electrochemical synthesis [11–14]. Silver nanoparticles have various important applications such as photographic process [15], surface-enhanced Raman spectroscopy [2] and catalysis [10].

Although silver nanoparticles of different shape and size have been successfully obtained through various methods, the concentration of nanosilver was several millimoles per liter or less in most of the procedures. Recently, concentrated dispersions of silver nanoparticles were prepared by simply aging an aqueous solution containing silver nitrate, urotropine, and PVP to synthesize flake-like silver nanoparticles in high concentration [16]. In this article, the submerged arc nanoparticle synthesis system (SANSS) method was used to prepare suspension nanoparticles [17,18]. This system consists of the heating source, a control unit, a pressure unit, a cooling unit, and an isothermal unit. The heating source provides the experimental process with a stable arc for metal vaporization. The control unit is used to modulate the process parameters, such as electric current, voltage, pulse-duration, off-time, feed speed, electrode gap, and the preparation time. The pressure unit is deployed to maintain a low pressure in the vacuum chamber. The isothermal system is to keep the media (deionized water and ethylene glycol) at a constant operation temperature. Meanwhile, the dielectric coolant is controlled at a low temperature to increase the nucleation of particles and restrain grain growth of nanoparticles. As compared to other synthesis methods, nanoparticles prepared by the SANSS are uniformly dispersed in the dielectric liquids. Therefore, the nanoparticles obtained possess steady suspension in the dielectric liquids and less particle aggregation occurs.

2. Experimental

The schematic diagram of SANSS is shown in Fig. 1. In the process, a pure silver bar is submerged in dielectric liquid as the electrode. The heating source generates an electrical arc with high-temperature from 6000 °C to 12,000 °C to heat the metals. Silver is melted and vaporized in the region of the arc generated where the cooling medium is also vaporized rapidly due to extremely high-temperature. The generated metal vapors can expand volume and create inertia force around the cooling medium. The high-pressure liquid vapor is capable

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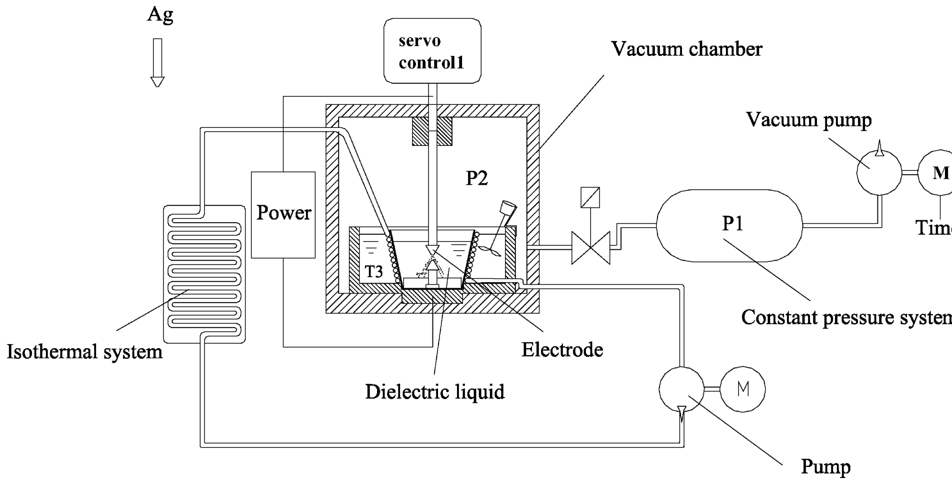

Fig. 1. Schematic diagram of SANSS.

of removing rapidly the vaporized silver from the arcing zone and cooling it immediately to restrain excess particle growth. Nanoparticles are then formed from the evaporated silver and are well dispersed in the cooling medium through three transformation stages, namely nucleation, growth, and condensation.

Because the dielectric liquid is kept at a low temperature, the vaporized metal can be condensed immediately by the coolant. Furthermore, vaporized silver particles are condensed in the cooling medium immediately after their nucleation. The size of the particles formed can be restrained within nano-scale and the condensed particles are well dispersed within the dielectric liquid without undesired particle aggregation.

To investigate the properties of nanoparticles in dielectric liquid, the silver nanofluids prepared in different dielectric liquids (deionized water and ethylene glycol) were analyzed by transmission electron microscope (TEM, JEOL2000FX), field emission scanning electron microscope (FESEM, JEOL JSM-6700F), X-ray diffraction (XRD, Japan MAC Sience, MXP18), UV–vis absorption spectrum (Thermo Spectronic, Helios Alpha) and viscosity (Brookfield Model PV-III+).

3. Results and discussion

Table 1 shows the experimental parameters deployed in this study. The minimal energy density (J_{min}) is proportional to the thermal conductivity (λ) and melting point (T_m) of the prepared material. Minimal machining energy density is 3.0×10^7 W/cm^2. In order to prepare silver nanoparticles, the pulse-on time and pulse-off time should be adequately decreased to enhance the discharge frequency and obtain higher energy density. It is clear that the manufacturing mechanism of silver nanoparticles mainly relies on the evaporation of raw materials at a high energy density. At applied current of 7.5 A, the finer particles can be obtained, and the thermal conductivity of the prepared particles is large. Furthermore, the condensation of particle is very fast. Thus, there is enough time to approach sphericity by surface tension. There is a high probability to get a small particle size at applied current of 7.5 A.

Table 1
Selected parameters used in the SANSS preparing silver nanofluid

Process parameters	Description
Working breakdown voltage, V	220 V
Electric current, I	7.5 A
On-time pulse duration, t_{on}	2 μs
Off-time pulse duration, t_{off}	2 μs
Pressure of chamber, P	30 Torr
Temperature of dielectric liquid, T	2 °C
Electrode diameter, D	5 mm
Dielectric liquid	Deionized water

The transmission electron microscope (TEM, JEOL2000FX) was also utilized to observe the nanorods structure. The morphology of silver nanoparticles prepared in deionized water revealed a spherical structure, with an average size of 6–25 nm,

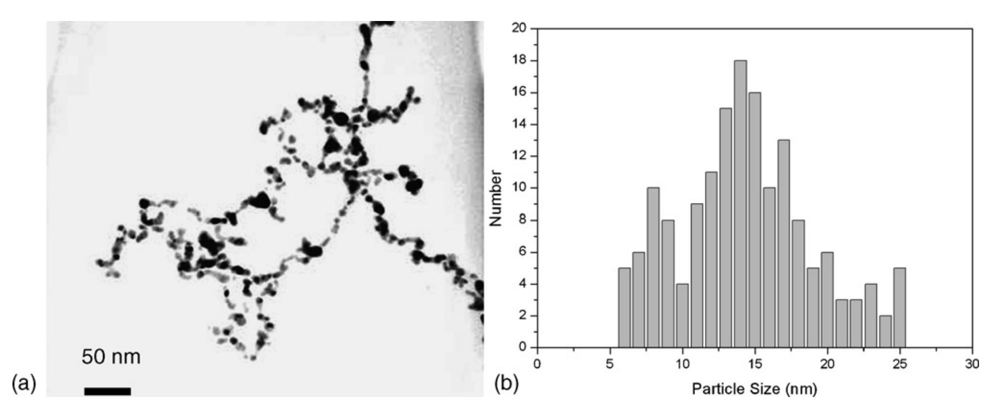

Fig. 2. (a) TEM images of the as-prepared silver nanoparticles. (b) The particle size distribution of the prepared silver nanoparticles.

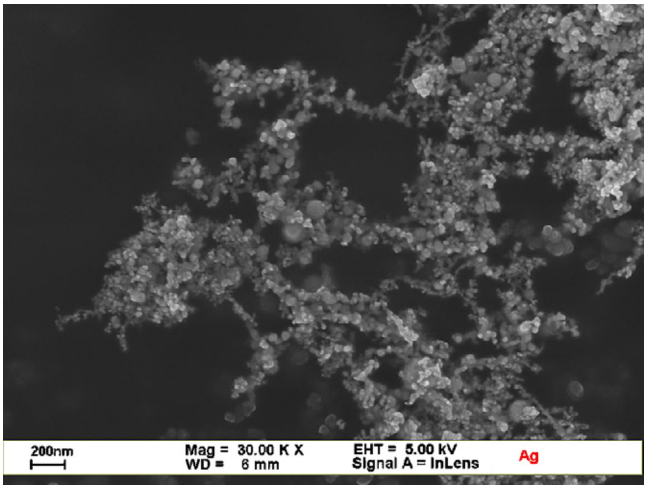

Fig. 3. FESEM image of the preparing silver nanoparticles.

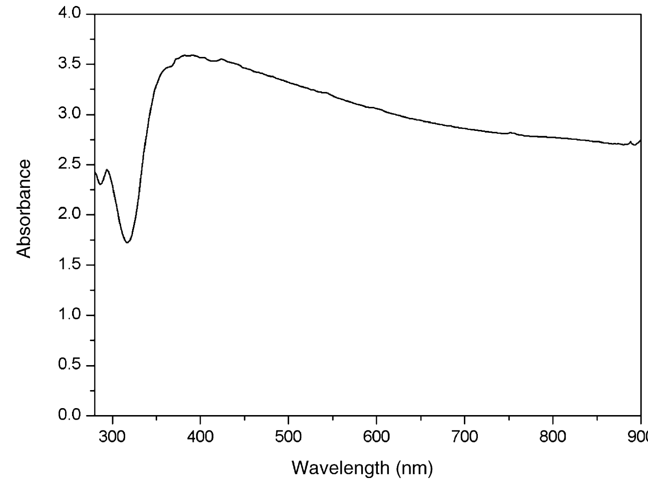

Fig. 5. The UV–vis absorption spectrum of silver nanofluid.

shown as in Fig. 2(a). After calculation of the particle size observed by TEM, the result is shown in Fig. 2(b). The morphology of the silver nanoparticles prepared in deionized water revealed a spherical structure, as reported in Fig. 3 (FESEM image). After analyzing the samples, we find the nanoparticles to have almost spherical shape. The producing of the nanoparticles is related to the properties of Ag. We know that the thermal conductivity of silver is higher than other materials. The condensation of the melted Ag is too rapid to form the sphere by means of surface tension.

The corresponding phases were identified with the X-ray diffraction method (XRD). The XRD (Japan MAC Sience, MXP18) was deployed to analyze the composition of silver nanoparticles. As shown in Fig. 4, the diffraction peaks were approximately identical to those of pure Ag. It was compared with the data of the JCPDS No. 04-0783, indexed with Ag (1 1 1), (2 0 0), (2 2 0), (3 1 1), (2 2 0), and (4 0 0) consistent with the standard values for bulk Ag. Thus, the results clearly showed that the as-prepared Ag nanoparticles were the face-centered cubic structure.

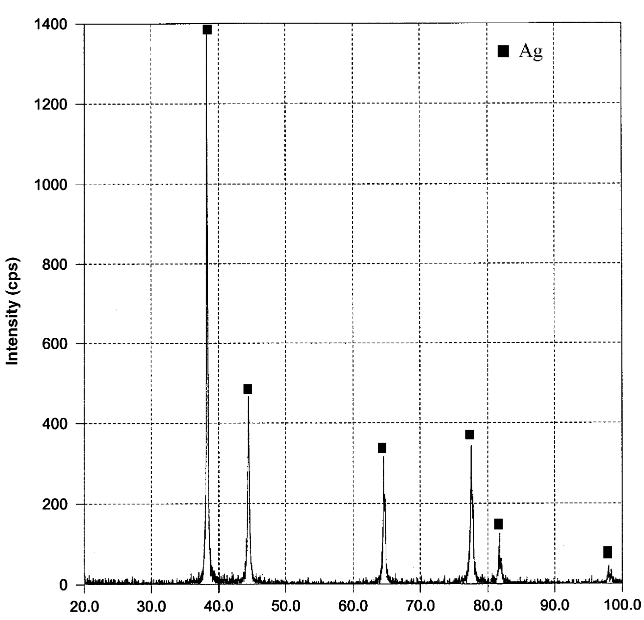

Fig. 4. Results of X-ray diffraction of as-prepared silver nanoparticles.

The silver nanoparticles were well dispersed in deionized water to form a transparent solution after using ultrasonic vibration for 15 min. The UV–vis absorption spectrum shown in Fig. 5 of the as-prepared silver nanoparticles dispersed in dielectric liquid (the concentration 0.5 vol.%) shows a broad absorption peak, whose center was at about 410 nm. The transmittance of light source on the nanoparticle suspension is less than 12%. In other words, the nanoparticle suspension produced by this study has a good capability of absorbing UV light.

Fig. 6 shows the relationship between viscosity and shear rate for the silver nanofluid and deionized water. As can be seen, there is no apparent change in the viscosity of the silver nanofluid and deionized water, but the silver nanofluid viscosity is still larger than the deionized water when the shear rate is raise. Thus, silver nanoparticles exist in the deionized water, affect the flow of the nanofluid, causing the viscosity to increase.

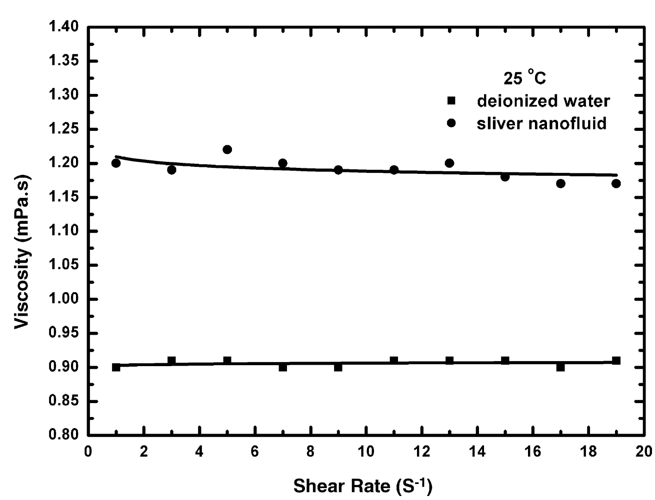

Fig. 6. Relationship between viscosity and shear rate for the silver nanofluid and deionized water.

4. Conclusions

The SANSS is a novel process to prepare well dispersed particles in the dielectric liquid. The size of particles produced by this method can be reduced to nano-scale. Silver nanoparticles with an average size of 6–25 nm have been successfully prepared by the submerged arc nanoparticle synthesis system (SANSS). Most important, the established SANSS is demonstrated to be effective in avoiding particle aggregation and producing uniformly distributed and well-controlled size of silver nanoparticles dispersed in deionized water suspension.

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