Preparation and dispersive properties of Ag colloid by electrical explosion of wire

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ABSTRACT

In this work, Ag colloid was prepared by electrical explosion of wire in deionized water with 0.2 mm and 0.3 mm wire diameter. The temperature of water used for medium of explosion process was change from 20 °C to 80 °C. Morphology and particle size of nanoparticles was observed by transmission electron microscope. The particle size and size distribution of nanoparticles was found to shift to a smaller size with a decrease of temperature and smaller wire diameter. Surface plasmon resonance of the silver colloids was studied by UV–vis spectroscopy. Stability of silver colloids was investigated by zeta-potential and Turbiscan techniques. The results indicated that temperature of medium during explosion affects much on the stability of Ag colloid. The silver colloidal stability prepared at lower temperature and smaller wire diameter was more stable.

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1. Introduction

Silver colloid has wide applications in a variety of fields such as catalyst, microelectronics, biology and medicine [1–4]. In these applications, the stability of colloids is one of the important parameters. Main approach to get higher stability is chemical surface treatments by using surfactants and/or dispersants. Surface-modified colloids may be used in microelectronic, catalytic, paints etc. However, in biomedical application, surfactants and/or dispersants may be destroyed or have bad effects on the cell or living body. Therefore, it is important to get the stable colloids without the additives and impurities. In addition, there has been an increased emphasis on the topic of "green" synthesis methods. These efforts aim at the total elimination or at least the minimization of hazardous waste and toxic chemicals. In this work, we present a totally green method for preparation of silver colloid.

Electric explosion of wire (EEW) is a top-down physical method for fabricating nanostructure materials [5]. The products of wire explosion process depend on the current density, wire dimension and the medium in which explosion is carried out. The electrical explosion of wires in gas atmospheres is used for preparing various metal and ceramic nanopowders. Ultra-fine metallic powder with size smaller than 100 nm was prepared by EEW in inert gas [6]. Nanosized compound nanopowders can be prepared by reaction between metal with gas. Nitride or oxide compounds formed when exploding in nitrogen or oxygen [7,8]. The particle size decreases with increasing input energy. The effects of working media (air and water) were examined by C. Cho et al. [9]. It is shown that the average particle size of the powder synthesized in the air is much bigger than that of powder prepared in water. Electrical explosion of wire in liquid is a useful method to prepare colloids. In this process, the nanoparticles directly disperse into the liquid and it can be expressed as one-step technique in which the nanoparticles are suspended directly into liquid and decrease the aggregation of nanoparticles and increase stability of colloids. Recent investigation of metal nanoparticles in liquid [10] shows that the use of EEW in liquid is able to prepare stable suspension. The stability of suspension obtained by EEW in liquid can be improved by using surfactant solution as a working liquid.

The present paper focuses on the preparation of silver colloid in deionized water with two kinds of wire diameter. The stability of colloid was investigated by changing only temperature. It introduces a green method to prepare colloid with non-toxic chemicals.

2. Experimental

Silver colloid was prepared using electrical wire explosion apparatus. This equipment was composed of a teflon beaker, an electrical discharge circuit and a spark gap switch. A schematic diagram of the experimental setup is shown in Fig. 1. The 400 mL teflon beaker was filled with DI water. The silver wire (⌀ 0.2 mm × 27 mm and 0.3 mm × 27 mm) was located between the electrodes, and then immersed in liquid. The 30 μF capacitor was charged up to 3 kV, and was driven through the wire in the pulsed form by the spark gap switch. Due to the resistance of the silver wire much smaller than that of the water, the electric energy was only deposited on the wire. Thus, only the wire between the electrodes is heated, vaporized, turned into plasma state and make a shockwave scatter to the ambient medium. The vapor colliding with the water cools down and condenses into nanoparticles. After 10 times of explosion, the suspension was collected for analysis. The experimental parameters of explosion process were summarized in Table 1.

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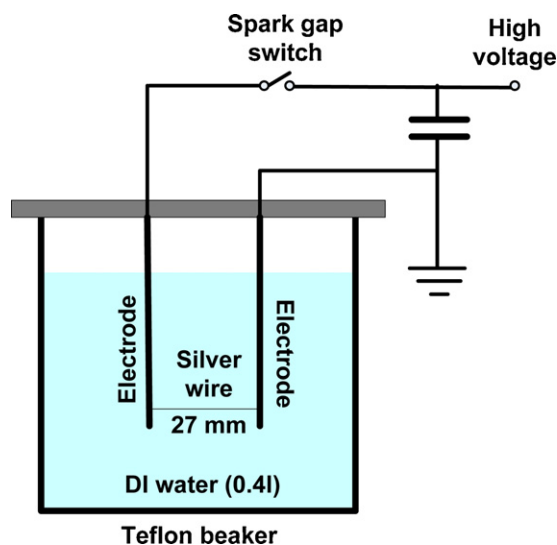E-mail address: jckimpml@ulsan.ac.kr (J.C. Kim).

Fig. 1. Schematic diagram of experimental setup for the wire explosion process in deionized water.

Table 1
Summary of experimental details.

Capacitance	30 µF
Charging voltage	3.0 kV
Material	Ag
Diameter	0.2 mm and 0.3 mm
Explosion time	10 times
Length of the exploded wire	27 mm
Ambient liquid	DI water (400 mL)
Ambient temperature	20, 40, 60, 80 °C

The morphology and the size of the prepared silver nanoparticles were observed by transmission electron microscopy (TEM). A drop of silver suspension was put on a carbon coated copper grid followed by drying under vacuum at room temperature and then subjected to electron-microscopic chamber for observation. Particle size distribution was analyzed from TEM images. Surface plasmon resonance (SPR) of the silver colloids was studied by UV–vis spectroscopy method in the wavelength range of 200–800 nm. The dispersion stability was measured using a Turbiscan Lab (Formulaction Co., France) based on multiple light scattering method. It can detect the concentration variation in the colloid by scanning the whole height of the sample in transmission and backscattering light.

3. Results and discussion

The Ag colloids were prepared by EEW in water at temperature in the range of 20–80 °C. Fig. 2 shows the absorption spectra of the Ag colloids prepared with 0.2 mm wire diameter. The absorbance peaks of them were listed in Table 2. It can be seen that all spectra have one absorbance peak around 400 nm. These absorption peaks known as surface plasmon resonance of silver nanopartciles have been presented in many literature [11–13]. The optical spectral feature confirms that the silver nanoparticles are formed in the liquid. It is well known that the maximum wavelength of SPR band and its bandwidth in the colloid depends on many factors such as particle size, shape and the ambient medium. We can clearly see the differences of absorbance spectra of Ag colloid prepared at different

Table 2
Absorbance values of Ag colloid prepared by EEW in DI water at different temperatures.

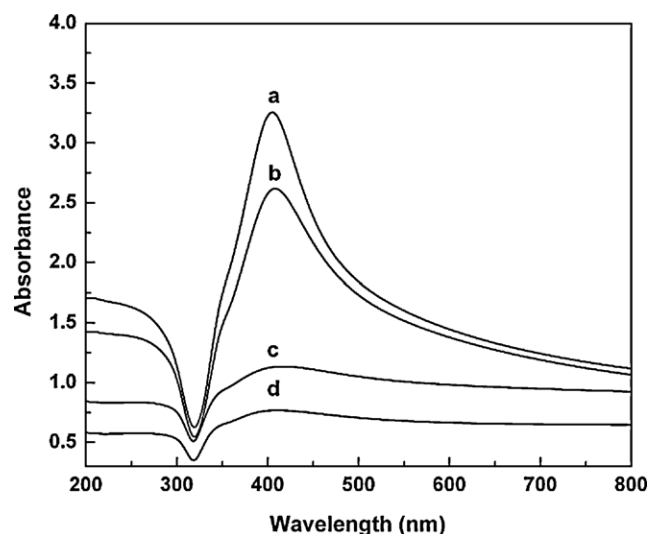| Temperature (°C)		20	40	60	80
Absorbance peaks (nm)	0.2 mm	405	408	416	410
	0.3 mm	406	406	421	424

Fig. 2. UV–vis spectra of the Ag colloids synthesized by EEW in deionized water at (a) 20 °C, (b) 40 °C, (c) 60 °C and (d) 80 °C with diameter of 0.2 mm.

temperature. When the medium temperature increased, the intensity of maximum wavelength of SPR decreased and the bandwidth increased. The wavelength band position possesses red-shift and changes from 405 nm to 416 nm with increasing temperature from 20 °C to 80 °C. Fig. 3 depicts the absorption spectra of Ag colloid prepared with 0.3 mm wire diameter. It reveals that the behavior of these is similar to one of the Ag colloid prepared with 0.2 mm wire diameter. The wavelength band positions are a little higher and changes from 406 nm to 424 nm in the temperature range from 20 °C to 80 °C. The influence of surrounding medium is neglected because the liquid of all colloid is pure water. Therefore, the differences among the spectra may be attributed to variation of particle size, shape and/or particle size distribution.

Fig. 4 shows TEM images and particle size distribution of silver nanoparticles in the colloidal suspension obtained by EEW in water at different medium temperatures. It can be seen in the TEM image that the silver nanoparticles are nearly in spherical shape. Variation of the average particle size and particle size distribution depends on the medium temperature. Average particle size decreased with increasing temperature. The average particle size changed from
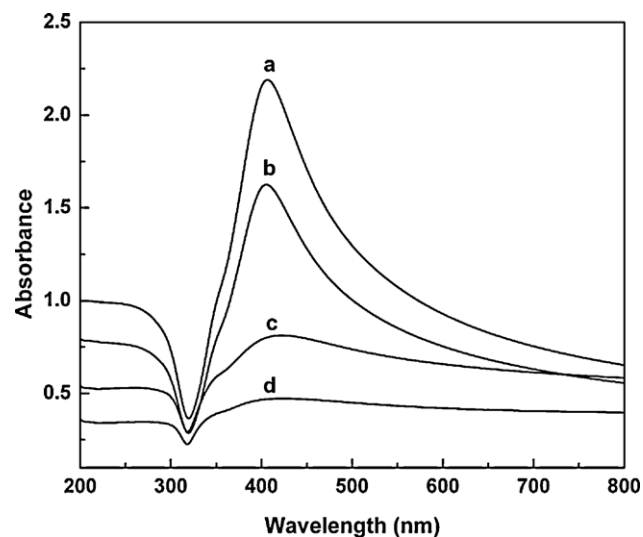

Fig. 3. UV–vis spectra of the Ag colloids synthesized by EEW in deionized water at (a) 20 °C, (b) 40 °C, (c) 60 °C and (d) 80 °C with diameter of 0.3 mm.
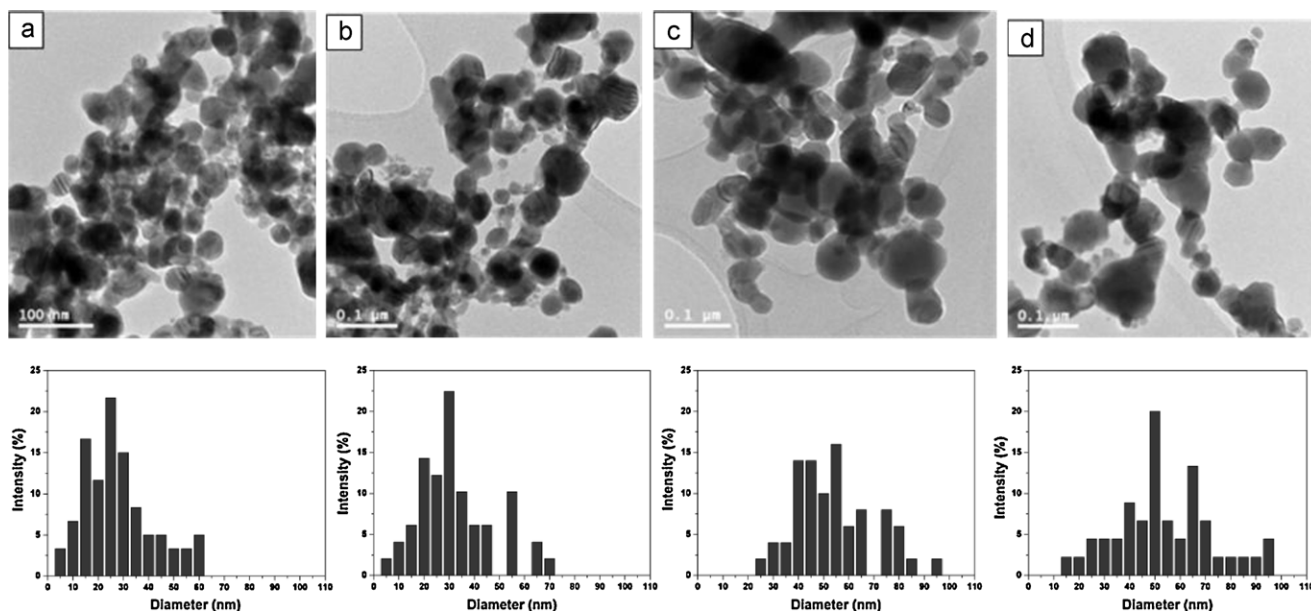
Fig. 4. Particle size distribution of silver nanoparticles prepared at different temperatures: (a) 20 °C, (b) 40 °C, (c) 60 °C and (d) 80 °C with diameter of 0.2 mm.

~37 nm to 54 nm for temperature of 20 °C and 80 °C, respectively. The histogram of diameter distributions demonstrated that more uniform size distribution was obtained at lower temperature. The particle size seems to extend to bigger size when synthetic temperature increases. The particles concentrated smaller size at lower synthetic temperature. At synthetic temperature of 20 °C and 40 °C, number of particles distributed almost in the range of 15–35 nm. This range shifted to higher value of 40–65 nm when the temperature increased to 60 °C and 80 °C. The theory predicts that when particles are bigger than a critical value (>20 nm) [11], the particles have extrinsic size effect [14]. The larger nanoparticles have higher surface plasmon peak and bandwidth is broader. These are in agreement with the UV–vis results which are mentioned above. The smaller average size and narrower size distribution of colloidal solution prepared at lower temperature cause the red-shift of the wavelength band position.

Fig. 5 presents the variation of transmission signal as a function of time for four silver colloids prepared in DI water at different temperatures: 20 °C, 40 °C, 60 °C and 80 °C (marked as samples a, b, c

and d) with wire diameter of 0.2 mm. It can be realized that the variation of the colloids samples a and b has the same behavior and little different speed of sedimentation. In these two cases, the percentage of light going across the sample gradually increases over time and the variation of transmission signal is linear with the time. The transmission signals of the sample a increased more slowly than that of sample b. In the case of higher temperature (samples c and d), the transmission signal quickly increased in around 13 h and then slowly went up. The variation of colloids of these two samples is almost alike. The difference between them is only speed of sedimentation of nanoparticles. This phenomenon can be attributed by two reasons. The first reason is the bigger particle size and broader size distribution as shown in the TEM analysis. The average particle size and size distribution of samples c and d are bigger than those of samples a and b (as seen in Fig. 4). The second reason is the zeta-potential of nanoparticles. At higher synthesis temperature, the samples c and d have zeta-potential values of −2.45 mV and −2.07 mV, respectively. They are small to keep the colloid stable. The zeta-potential of samples a and b is −25.78 mV and −15.47 mV, which are much higher absolute values than that of samples c and d. The higher absolute value of zeta-potential can prevent agglomeration of nanoparticles. The agglomeration of silver nanoparticles into bigger clusters can cause the fast sedimentation.

Fig. 6 shows the TEM images of silver nanoparticles prepared by EEW with 0.3 wire diameter. It indicates the particle size and size distribution of the nanoparticle. It can be seen in the TEM results that the particle size and size distribution of the nanoparticles are same trend with the case of 0.2 mm wire diameter but bigger particles size and broader size distribution. When the diameter changed from 0.2 mm to 0.3 mm, the average size increased from 37 nm to 40 nm at synthetic temperature of 20 °C and increased from 54 nm to 68 nm at synthetic temperature of 80 °C. Bigger wire diameter reduces the energy deposited on the wire when the same input energy is applied to the wire. The volume of plasma/vapor remains almost constant though the wire diameter is changed [15]. Therefore, the density of the plasma formation increases and this can be a reason to grow particle size. Other reason can be explained by droplet formation of the wire. When the explosion occurs during expanding volume and plasma formation, a part of wire near electrodes does not form vapor state. This part becomes only liquid phase. Bigger wire is used, more liquid droplet forms. The liquid
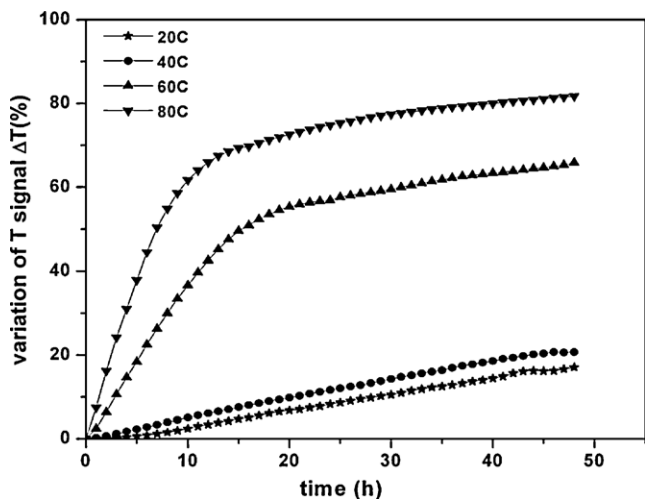

Fig. 5. Variation of transmission signal (ΔT) vs. time for silver colloid prepared by EEW in water at different temperatures with 0.2 mm wire diameter.
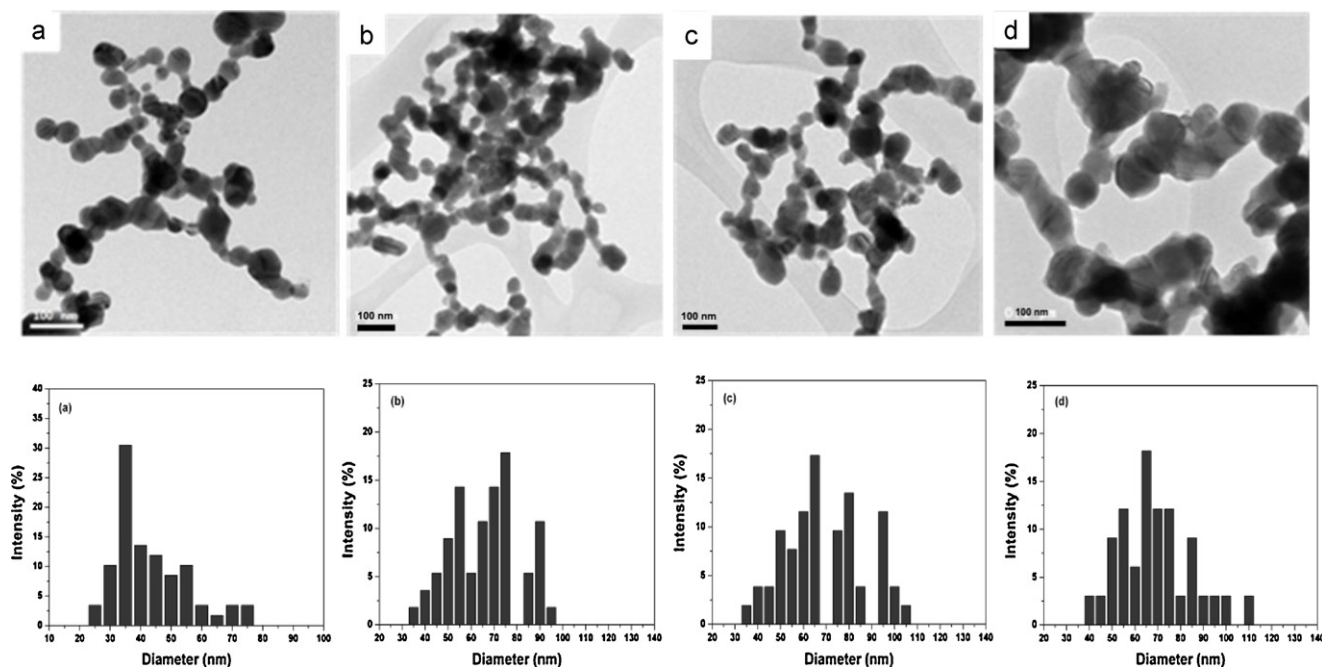
Fig. 6. Particle size distribution of silver nanoparticles prepared at different temperatures: (a) 20 °C, (b) 40 °C, (c) 60 °C and 80 °C with diameter of 0.3 mm.

droplets condense to big particles. Fig. 7 shows the variation of transmission signal as a function of time for silver colloid prepared with 0.3 mm wire diameter at different temperatures: 20 °C, 40 °C, 60 °C and 80 °C (marked as samples e, f, g and h). The behavior of sedimentation is the same in samples f, g and h. The transmission signals dramatically increased in about 15 h and then slightly rise. Stability of sample e is different with that of others. The transmission signal gradually goes up with the time. The stable behavior of silver colloid prepared with different wire diameter is almost the same. The difference is just the speed of sedimentation. The transmission signal of colloid prepared with smaller size diameter changed less than that of colloid prepared with bigger one. The particle size and size distribution of silver particles prepared with smaller size diameter are better therefore, they make the colloid more stable.
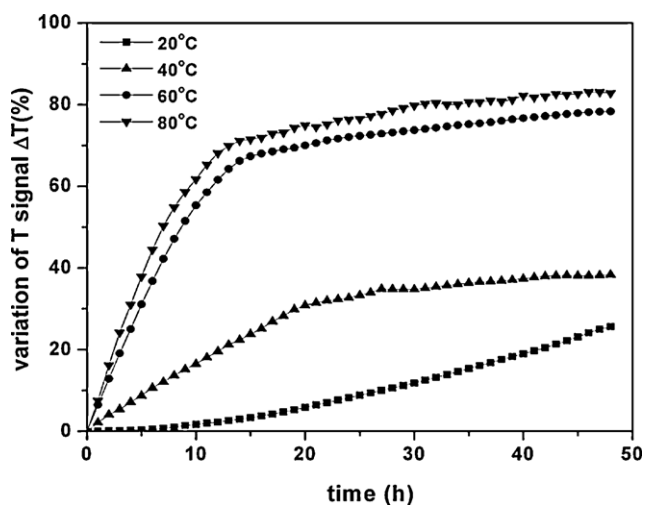
4. Conclusions

The silver colloids were prepared by electrical explosion of wire in water in the range temperature of 20–80 °C with wire diameter of 0.2 mm and 0.3 mm. The prepared nanoparticles were characterized by transmission electron microscope and properties of colloids were analyzed by optical absorption, zeta-potential and multiple light scattering. The particle size distribution and average particle size depends on temperature of medium and wire diameter. The lower temperature and smaller diameter make smaller size and narrower size distribution. The temperature of the explosion medium affects the stability of the silver colloid. The more stable silver colloid is obtained with lower temperature of explosion medium and smaller wire diameter. This research shows a simple, effective and "green" method to prepare the silver colloid.

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Fig. 7. Variation of transmission signal (ΔT) vs. time for silver colloid prepared by EEW in water at different temperatures with 0.3 mm wire diameter.

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