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# Colloidal Synthesis and Structural Characterizations of Silver Nanoparticles by using Wet Chemistry

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**Abstract:** In this paper we present the synthesis of silver nanoparticles colloids by using wet chemistry method. Silver nanoparticles were successfully prepared in an aqueous system at room temperature and under ambient pressure. The colloidal silver was incorporated by dip-coating to the glass substrate. The product was characterized with X-ray diffraction (XRD), Atomic Force Microscopy (AFM), thermal gravimetric analysis (TGA). X-ray diffraction spectrum of the nanoparticles confirmed the formation of face-centered-cubic form of metallic silver nanoparticles with preferred orientation along (111) plane. The Atomic Force Microscopy shows that the silver nanoparticles are of spheric and relatively uniform. The optimum molar ratio [Urea]/[Ag+] and molecular weight of PVP for the formation of Ag nanoparticles in various solutions were [Urea]/[Ag+]=4 and PVP=55000 which optimize the formation efficiency, reduces the size, enhance dispersity and prevents aggregation of the prepared nanoparticles.

**Key Words:** Silver NanoParticles (SNPs), Wet Chemistry (WC), Atomic Force Microscopy (AFM), X-ray diffraction (XRD), Thermo-gravimetric analysis (TGA), polyvinyl pyrrolidone (PVP), Urea; Dextrose.

## **1. Introduction**

Noble metal nanoparticles materials have been the focus of intense research in recent decade, and it is motivated by the exceptional properties that a material gains when its size is reduced to nanoscale lengths. For example, nanoparticles present a higher surface to volume ratio with decreasing size of nanoparticles. Specific surface area is relevant for catalytic and other related properties such as antimicrobial activity in silver nanoparticles (SNPs). The remarkable physical, chemical, electronic and optical properties of silver nanomaterials<sup>1</sup> allows for their utilization in various scientific applications such as sensors<sup>2</sup>, nanophotonics devices<sup>3</sup>, biology<sup>4</sup>, drug delivery<sup>5</sup>, cancer treatment<sup>6</sup>, photo-thermal therapy<sup>7</sup>, diabetic healing<sup>8</sup>, solar cells<sup>9</sup>, catalysis<sup>10</sup>, cooling system<sup>11</sup>, surface-enhanced Raman spectroscopy<sup>12</sup>, inkjet-printer<sup>13</sup>, imaging sensing, biology and medicine<sup>14</sup>, ptoelectronics and magnetic devices<sup>15</sup>. These properties significantly depend on the size, shape and surface chemistry of the nanomaterials. Synthesis of Silver particles is an important task. Several methods have been used in the past to prepare nanostructured silver particles, including chemical reduction<sup>16</sup>,

electrochemical reduction<sup>17</sup>, heat evaporation<sup>18</sup>, thermal decomposition in organic solvents<sup>19</sup> polyol process<sup>20</sup> chemical and photo-reduction in reverse micelles<sup>21,22</sup>; and radiation chemical reduction<sup>23,24</sup>. All these methods of preparation involve the reduction of relevant metal salts in the presence or absence of surfactants, which is necessary in controlling the growth of metal colloids through agglomeration. From a practical point of view, the method of chemical reduction from aqueous silver nitrate solution is most preferable for obtaining silver nanoparticles. In a typical process, one can choose the reducing agent and corresponding protective agent to obtain a uniform dispersion of products. In an aqueous reaction medium, when a strong reducing agent such as sodium borohydride (NaBH<sub>4</sub>) or hydrazine (N<sub>2</sub>H<sub>4</sub>) is used, the fast reaction produces very small primary particles, and when the precursor (i.e.  $AgNO_3$ ) concentration is relatively high, it becomes difficult for the protective agent, e.g. PVP molecules, to fully adsorb onto the silver colloidal surface in time due to the diffusion limit. As a result, the conversion might prove high, but the size distribution of the final product is often very broad<sup>25,26</sup>. In order to avoid too much agglomeration, the silver ion concentration must be kept low, which in turn compromises the productivity of the process. However, when a moderate reductant such as formaldehyde is used, one can obtain silver particles with a mean size of 27.8 nm and standard deviation of 9.9 nm from an initial silver concentration of  $0.1 \text{ M}^{27,28}$ . Panigrahi *et al* (2004) tried a weak reductant, i.e. glucose, to obtain Ag particles of about 20 nm in size, but the products were not uniform enough<sup>29</sup>. Nersisyan et al (2003) also used glucose, however their precursor was  $Ag_2O$  and the Ag particles were in the range of 10–50  $nm^{25}$ . Hu *et al* (2004)<sup>30</sup> used trisodium citrate to prepare silver nanorods and nanowires based on the principles of slow reduction rate and non-isotropic adsorption of surfactant<sup>27,31</sup>. Silvert *et al* (1996) obtained fine sized Ag particles whose size distribution was between 15 and 36 nm by polyol reduction<sup>32</sup>. Despite these efforts, it remains difficult to prepare silver particles of less than 20 nm and with a narrow distribution from an aqueous solution. In the present work on the preparation of nano-sized silver nanoparticles from aqueous solution of silver nitrate, we employed as reductant dextrose (reducing agent), polyvinyl pyrrolidone (PVP) was employed as a stabilizer (protective agent or capping agent). In this work, we study the effect of the PVP molecular weight  $(M_w = 10000, 29000, 40000, and 55000)$  on the formation of silver nanoparticles. We use the urea as an additive to produce intermediates that slow the transformation of silver ions into silver by the reducing agent, which is dextrose in this case. Due to this change in reaction path, we can obtain silver colloids of small particle sizes and a narrow distribution using only a small amount of protective agent while maintaining high conversion rates at reasonable silver concentrations at the same time.

## 2. Experimental materials and methods

**Chemicals:** All of the chemicals used in the experiment were analytic reagent (AR). The silver nitrate was used as the precursor to prepare silver colloids and provided by Hubei Xinying Noble Metal Co. Ltd. Dextrose, was used as the reducing agent and polyvinyl pyrrolidone (PVP) as the stabilizing agent for these Ag colloids were obtained from Sigma-Aldrich. The sodium hydroxide was used to promote the reduction reaction at room temperature and purchased from Tianjin Chemical Reagent Corp.

**Preparation of nano-Ag** :We prepared three separate solutions, i.e. A, B and C. Solution A contained 0.156 M AgNO<sub>3</sub> with variable quantities of urea (the molar ratio of [Urea]/  $[Ag^+]$  was between 0 and 12). Solution B contained polyvinyl pyrrolidone (PVP) with its quantity fixed at 1g PVP/1g AgNO<sub>3</sub> and variable quantities of NaOH, whose concentration was from 0.2 to 1M PVP having molecular weights (MW) of 10,000, 29,000, 40,000 and 55,000 were tested in this work for their capability to stabilize the silver colloidal suspensions. Solution C contained 0.334 M dextrose (C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>). The Particular experimental conditions are listed in Table 1 (sample Nos 1-12) at the ambient temperature, and with stirring at 600 rpm. Solution A was rapidly poured into solution B. Light yellow precipitates formed immediately. After reacting for 10 min, solution C was poured into the mixed solution of A and B. After 5 minutes of interaction we transferred the mixture to water bath at 70 °C to accelerate the reduction reaction. Then note that the color changed from yellow to black. After half an hour, the silver colloids were separated from the solution by vigorous centrifugation at 10,000 rpm for 60 min to remove any excess protecting agent and then re-dispersed in D.I. water. Then repeat the previous operation at the speed 10,000 for a period of half an hour, to remove as much of the PVP as possible, then re-dispersion in D.I. water again. For further analysis, the precipitate was also separated by centrifugation at 10,000 rpm for 30 min and dewatered by heating at 100 °C for several hours.

No.	AgNO <sub>3</sub>	PVP/AgNO <sub>3</sub>	MW	Urea/AgNO <sub>3</sub>	Dextrose	NaOH
	(M)	(g/g)	PVP	(Molar ratio)	(M)	(M)
G1	0.156	1/1	10000	0	0.334	0.0125
G2	0.156	1/1	29000	0	0.334	0.0125
G3	0.156	1/1	40000	0	0.334	0.0125
G4	0.156	1/1	55000	0	0.334	0.0125
G5	0.156	1/1	10000	4	0.334	0.025
G6	0.156	1/1	29000	4	0.334	0.025
G7	0.156	1/1	40000	4	0.334	0.025
G8	0.156	1/1	55000	4	0.334	0.025
G9	0.156	1/1	10000	12	0.334	0.05
G10	0.156	1/1	29000	12	0.334	0.05
G11	0.156	1/1	40000	12	0.334	0.05
G12	0.156	1/1	55000	12	0.334	0.05

Protocol: Theoretically, urea in solution can decompose to ammonium and cyanate ions:

 $(NH_2)_2 CO \rightarrow NH_3 + HOCN$ 

In an alkaline solution, cyanate ions react with hydroxide ions to form carbonate ions and ammonium according to:

 $O \ C \ N^{-} + O \ H^{-} + H_{2} O \rightarrow C \ O_{3}^{2-} + N \ H_{3}$ 

The decomposition rate of urea increases as pH or temperature increases; therefore, when solution A was injected into solution B whose pH was increase gradually, the alkaline solution accelerated the urea decomposition greatly and immediately produced many cyanate ions and carbonate ions. In addition, the Ksp values of AgOCN and Ag<sub>2</sub>CO<sub>3</sub> were both smaller than that of Ag<sub>2</sub>O. As a result, the intermediates of AgOCN and Ag<sub>2</sub>CO<sub>3</sub> were observed, instead of Ag<sub>2</sub>O. In the presence of a reducing agent (i.e. after adding solution C), this intermediate proved unstable, and it gradually converted into silver leading to a change of color from yellow to brown to black.

$$Ag^{+} + PVP + CH_{2}OH - (CHOH)_{4} - CHO + 2OH^{-}$$
  
$$\rightarrow CH_{2}OH - (CHOH)_{4} - COOH + Ag(PVP) + H_{2}OH^{-}$$

**Characterizations:** The structural properties of NSPs were investigated by X-ray diffraction (XRD, Philips, PW1710, Netherlands) that was operated at a voltage of 40 kV and a current of 30 mA with an excitation source of  $CuK_{\alpha}$  radiation ( $\lambda = 1.54060A^{\circ}$ ), in the range of scanning angle  $30-85^{\circ}$  at a scan rate of  $1^{\circ}$  / min with the step width  $0.02^{\circ}$ . The surface morphology was determined from the Atomic Force Microscopy measurements (AFM, Nanosurf easyScan2, Switzerland). The AFM measurements were performed in contact mode.

**Deposition of silver nanoparticles:** deposition of silver nanoparticles was performed by spin-coating. We coated the Ag colloidal onto glass substrates of the dimension of 25.4 mm x 76.2 mm x 1 mm were degreased in ethanol for 10 min and then ultrasonically cleaned with distilled water for another 15 min before deposition of films.

The spin-coating process was used for the deposition of the silver sols on to the substrates. Typically, a few drops of solution are placed on to the surface of the substrate; the initial amount of silver sol has little effect on the final film properties. The substrate is then rotated at several thousand rpm in order to obtain a homogeneous film.

#### 3. Results and discussion

#### **1.3 X-Ray Diffraction Analysis**

The X-ray diffraction pattern measurements of spin-coating silver nanoparticles film on glass substrate. The XRD measurements were performed in order to investigate the structural properties of the NSP. X-ray diffraction patterns of the various components, *i.e.* pure silver, and Ag nanoparticles, are presented in Figure 1, the value of the Ag lattice constant has been estimated to be a=4.078 A<sup>0</sup>, a value which is consistent with a=4.0862 A<sup>0</sup> reported by the (JCPDS cards 4-0783). XRD patterns of silver particles will yield five peaks from 30 to 85°,  $2\theta = 38^\circ$ , 44°, 64°, 77°, and 81° reveal that it is a face centered cubic (FCC) structure.



Figure1: XRD patterns of a pure silver with all synthesized silver nanoparticles

The discernible peaks can be indexed to (111), (200), (220), (311) and (222) planes of a cubic unit cell, which corresponds to cubic structure of silver (JCPDS card. No. 89-3722). The results show that the dominant faces of silver spheres are (111). The peak broadening, mean size of the crystallites was determined from X-ray diffraction data at (111) plane for all samples using Scherrer equation and results are given in the table 2.

$$D = \frac{K \lambda}{\beta COS\theta} , \qquad \beta = \sqrt{\beta_m^2 - \beta_a^2}$$

where *K* is a constant,  $\beta_m$  is full width at half maximum (FWHM) in degree (get it from fitting peaks according to Gaussian),  $\beta_a$  is a constant  $(\beta_a = 2.74 \times 10^{-3} rad)$  determine from the instrument broadening,  $\lambda$  is the wavelength of X-ray used,  $\theta$  is the Bragg angle. *K* value is taken as 0.9 for the calculations. The equation (1) was used for the calculation of the crystallite sizes. The particle sizes of all the samples in our study have been estimated by using the above Scherrer's equation and was found to be ~19 nm for the molar ratio  $[Urea]/[Ag^+] = 4$  and molecular weight of PVP = 55000.

No.	20	$\beta$ (FWHM)	Crystallite Size
	by degree	$\mathcal{P}_m$ (1 with with with with with with with with	(nm)
G1	38.134	0.322	30
G2	38.386	0.235	48
G 3	38.254	0.245	45
G 4	38.224	0.446	20
G 5	37.775	0.372	25
G 6	38.229	0.341	28
G 7	38.3122	0.332	30
G 8	37.837	0.476	19
G 9	37.581	0.356	26
G 10	38.205	0.236	48
G 11	38.31	0.253	42
G 12	38.109	0.239	47

Table 2. Crystallite sizes, diffraction angle and FWHM of synthesized silver nanoparticles

### 2.3 . AFM characterization

A  $2\mu m \times 2\mu m$ , AFM image is reported on Fig.2. A statistical treatment of AFM images was performed, using specially designed image processing software. To further exploit these measures should be extracted from these images the main geometrical characteristics of these nanostructures. These are summarized in Table 3. The silver nanoparticles have an average diameter ranged from 79 to 116 nm and an average height varied from 9 to 26 nm.



Figure 2. Two-dimensional AFM surface images of SNPs colloids deposited on a glass slide.

From the AFM pictures we can see that the size of nanoparticles is bigger. Silver nanoparticles tend to form aggregates on the surface during deposition. The sizes of Nanoparticles obtained from the AFM images appear much brighter than the values that we get from XRD measurements. We interpret those results to several reasons; first explanation relates the silver nanoparticles appear to be clustered together. Second explanation due to the wafers was not completely cleaned for PVP. Third reason related to the shape of the tip AFM may cause misleading cross sectional views of the sample. So, the width of the nanoparticle depends on probe shape; however, the nanoparticle height is independent of the probe shape. The finally explanation relates residual

amount of PVP on the both wafer and nanoparticles which could distort the results obtained from the AFM images.

No.	Mean AFM diameter	Mean AFM height
	(nm)	(nm)
G1	86	9
G2	79	10
G 3	114	26
G 4	81	10
G 5	93	13
G 6	95	12
G 7	102	14
G 8	90	10
G 9	95	13
G 10	103	14
G 11	116	12
G 12	98	11

Table 3. Average diameter and height of the silver nanoparticles calculated by AFM

#### **3.3** Thermo-gravimetric analysis (TGA)

TGA measurements were carried out on the Ag/PVP nanoparticles and pure PVP. A known weight of the samples was heated at a rate of 10°C min<sup>-1</sup> in flowing N<sub>2</sub>, from room temperature up to 700°C, which is in between the boiling point of the solvent and the degradation temperature of the polymer. Figure 3 shows three distinct stages of weight loss were observed for PVP. An initial weight loss was calculated to be around 7.3% in the range of room temperature up to 250°C. The weight loss up to this range of temperature is attributed to low molecular weight oligomers, loss of moisture and residual solvent in this range of temperature. Second stage was 11.5% in the range of 250°C up to 396°C, and third stage was 61% in the range of to 396°C up to 695°C for PVP.



Figure 3. TGA analysis of an Ag/PVP nanoparticle sample.

Figure 3 also shows one distinct stages of weight loss were observed for Ag/PVP nanoparticles. The only weight loss was about 4.1% in the range of room temperature up to 510°C. The second weight loss for PVP indicates that the pure PVP began to degrade above 300°C and is completely decomposed at above 695°C. The second major weight loss was attributed to structural decomposition of polymer. However, the thermo gravimetric analysis of the Ag/PVP nanoparticles showed decomposition profile starting at about 350°C and continuing until about 510°C. This shows that the thermal stability of the polymer is improved due to presence of Ag as nano-filler. This observation is consistent with the results obtained by (Mbhele *et al.*, 2003<sup>33</sup> and Steve Lien-Chung Hsu *et al.*, 2011<sup>34</sup>), where it has been shown that the PVA alone starts decomposing at about 280°C and its composite with about <1% Ag starts decomposing at higher temperature than the PVA alone, typically about 40°C more. In our experiments, though the content of Ag is expected to be more but it appears that the degradation temperature of our composite is sparingly higher to that it is reported. Finally, from TGA data summarized in Fig 3 shows that the residual PVP on silver is about 5 wt% for most samples, which is estimated to be the weight loss between 350 and 700°C. In general, the residual quantity of PVP greatly depends upon the washing procedure. This reason clearly explains the large difference in the result of the size nanoparticles obtained from XRD and AFM.

## Conclusion

In conclusion, the Ag nanoparticles have been prepared by the wet chemical technique under optimized conditions of preparation. Deposition of silver sols was carried out from aqueous solutions using silver nitrate, dextrose, PVP and sodium hydroxide. XRD as well as Atomic AFM image studies confirmed the nanometer size Ag particles. XRD analysis showed the nanoparticles were crystalline and metallic with minimum size ~19 nm. AFM analysis showed that most of the particles were spherical in shape with and their size appears larger than the calculated value from XRD. However, the nano-size particles calculated by XRD correspond reasonably well with the real values of the size SNPs.In summary, we have shown a drastic effect of the molar ration of [Urea]/[Ag+] and the

molecular weight of PVP on the size of silver nanoparticles. TGA results confirmed the weight loss of the sample occurred in temperature up to 250°C.

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## References

- 1. Mohd Abdul Majeed Khan, Sushil Kumar, Maqusood Ahamed, Salman A Alrokayan and Mohammad Saleh AlSalhi, "Structural and thermal studies of silver nanoparticles and electrical transport study of their thin films", Nanoscale Research Letters (2011), 6:434.
- 2. M. Shao, L. Lu, H. Wang, S. Luo & D. D. Ma, "Microfabrication of a new sensor based on silver and silicon nanomaterials, and its application to the enrichment and detection of bovine serum albumin via surface-enhanced Raman scattering", Microchim Acta 164 (2009) 157–160.
- 3. J. Prikulis, F. Svedberg, M. Kall, "Optical Spectroscopy of Single Trapped Metal Nanoparticles in Solution", Nano Letters 4 (2004) 115-118.
- 4. J. L. Elechiguerra, J. L. Burt, J. R. Morones, A. C. Bragado, X. Gao, H. H. Lara and M. J. Yacaman, "Interaction of silver nanoparticles with HIV-1", Journal of Nanobiotechnology 3 (2005) 1-10.
- 5. M. Arruebo, R. F. Pacheco, M. R. Ibarra, and J. Santamaria "Magnetic nanoparticles for drug delivery", nanotody 2 (2007) 22-32.
- 6. P. Jain, I. El-Sayed, M. El-Sayed "Au NPs target cancer", Nanotoday 2 (2007) 18-29.

- 7. X. Huang, M. A. El-Sayed, "Gold nanoparticles: Optical properties and implementations in cancer diagnosis and photothermal therapy", Journal of Advanced Research 1 (2010) 13–28.
- 8. M. Mishra, H. Kumar, K. Tripathi, "Diabetic delayed wound healing and the role of silver nanoparticles", Digest Journal of Nanomaterials and Biostructures 3 (2008) 49–54.
- 9. S. W. Tong, C. F. Zhang, C. Y. Jiang, G. Liu, Q. D. Ling, E. T. Kan, "Improvement in the hole collection of polymer solar cells by utilizing gold nanoparticle buffer layer", Chemical Physics Letters 453 (2008) 73–76.
- 10. [10] D. B. Sanchez, "The Surface Plasmon Resonance of Supported Noble Metal Nanoparticles: Characterization, Laser Tailoring, and SERS Application", PhD thesis, Madrid University (2007).
- 11. S. K. Das, S. U. Choi, W. Yu, T. Pradeep, "Nanofluids-Science and Technology", A John Wiley & Sons, INC. Publication (2007).
- 12. H. Cui, P. Liu and G. W. Yang, "Noble metal nanoparticle patterning deposition using pulsed-laser deposition in liquid for surface-enhanced Raman scattering", applied physics letters 89 (2006) 153124.
- A. Kosmala, Q. Zhang, R. Wright and P. Kirby, "Development of high concentrated aqueous silver nanofluid and inkjet printing on ceramic substrates", Materials Chemistry and Physics, volume 132, Issues 2-3, 15 February (2012), Pages 788-795.
- 14. P. K. Jain, X. Huang, I. H. EL-Sayed and M. El-Sayed, "Noble Metals on the Nanoscale: Optical and Photothermal Properties and Some Applications in Imaging, Sensing, Biology, and Medicine", American Chemical Society Acc. Chem. Res. 41 (2008) 1578–1586.
- 15. A.I. Maaroof, G.B. Smith, "Effective optical constants of nanostructured thin silver films and impact of an insulator coating", Thin Solid Films 485 (2005) 198 206.
- 16. Marzan, L. M. L. Lado-Tourino, I, "Reduction and stabilisation of silver nanoparticles in ethanol by nonionic surfactants", Langmuir, 1996, 12(15), 3585-89.
- 17. Rashid A. Khaydarov, Renat R, Khaydarov, Olga Gapurova, Yuri Estrin, Thomas Scheper, "Electrochemical method for the synthesis of silver nanoparticles", Nanopart Res (2009) 11:1193– 1200.
- 18. Smetana, A. B.; Klabunde, K. J. & Sorensen, C. M, "Synthesis of spherical silver nanoparticles by digestive ripening stabilization with various agents and their 3-D and 2-D superlattice formation", J. Colloid Interface Sci., 2005, 284(2), 521-26.
- 19. Lee, K. J.; Jun, B. H.; Choi, J.; Lee, Y. I.; Joung, J. Oh, Y. S, "Environmentally friendly synthesis of organic soluble silver nanoparticles for printed electronics", Nanotechnology, (2007), 18, 335601 (5pp).
- 20. Silvert, P. Y.; Herrera-Urbina, R.; Duvauchelle, N. Vijayakrishnan, V., "Preparation of colloidal silver dispersions by the polyol process", Part 1.Synthesis and characterization. J. Mater. Chem., 1996, 6(4), 573-78.
- 21. Ohde, H.; Hunt, F. & Wai, C. M., "Synthesis of Silverand Copper Nanoparticles in a Water-in-Supercritical-Carbon Dioxide Microemulsion", Chemistry.Materials., 2001, 13(11), 4130-35.
- 22. Sun, Y. P.; Atorngitjawat, P. Meziani, M. J., "Preparation of silver nanoparticles via rapid expansion of water in carbon dioxide microemulsion into reductant solution". Langmuir, 2001, 17(19), 5707-10.
- 23. Henglein, A, "Reduction of Ag(CN)<sub>2</sub> on silver and platinum colloidal nanoparticles". Langmuir, 2001, 17(8), 2329-33.
- 24. Henglein, A., "Colloidal silver nanoparticles: Photochemical Preparation and Interaction with O<sub>2</sub>, CCl<sub>4</sub>, and some metal ions". Chemistry Material, 1998, 10(1), 444-50.
- 25. Nersisyan HH, Lee JH, Son HT, Won CW, Maeng DY, "A New and Effective Chemical Reduction Method for Preparation of Nanosized Silver Powder and Colloid Dispersion". Mater. Res. Bull, 2003 38 (6): p. 949-956.
- 26. N.Pradhan, A. Pal and T. Pal, "Silver nanoparticle catalyzed reduction of aromatic nitro compounds" Colloids and Surfaces A: Physicochemical and Engineering Aspects vol 196, 2002, pp.247-257.
- 27. Chou K-S, Lai Y-S, "Effect of polyvinyl pyrrolidone molecular weights on the formation of nanosized silver colloids". Mater Chem Phys, 2004 83(1): p. 82-88.

- 28. Chou K-S, Lu Y-C, Lee H-H, "Effect of alkaline ion on the mechanism and kinetics of chemical reduction of silver". Mater Chem Phys, 2005 94(2–3): 429-433.
- 29. Panigrahi S, Kundu S, Ghosh S, Nath S, Pal T, "General method of synthesis for metal nanoparticles". Journal of Nanoparticle Research, 2004 6(4): p. 411-414.
- 30. Hu J-Q, Chen Q, Xie Z-X, Han G-B, Wang R-H, Ren B, Zhang Y, Yang Z-L, Tian Z-Q, "A Simple and Effective Route for the Synthesis of Crystalline Silver Nanorods and Nanowires". Advanced Functional Materials, 2004 14(2): 183-189.
- 31. Lu, YC, Chou, KS, "A simple and effective route for the synthesis of nano-silver colloidal dispersions". J Chinese Inst Chem Eng, 2008 39: p. 673–678.
- 32. Silvert PY, Herrera-Urbina R, Duvauchelle N, Vijayakrishnan V, "Preparation of colloidal silver dispersions by the polyol process". J Mater Chem, 1996 6(4), 573-78.
- Mbhele ZH, Salemane MG, van Sittert CGCE, Nedeljkovic JM, Djokovic V, Luyt AS, "Fabrication and Characterization of Silver-Polyvinyl Alcohol Nanocomposites". J. Chem. Mater. 200315: 5019-5025.
- 34. Steve Lien-Chung Hsu, Rong-Tarng Wu, "Preparation of Silver Nanoparticle with Different Particle Sizes for Low-Temperature Sintering", 2010 International Conference on Nanotechnology and Biosensors IPCBEE vol.2 (2011) © (2011) IACSIT Press, Singapore.

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