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Concentration Effect on The Thin Films of Silver Nanowires Fabricated Using Meyer-rod Coating

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Abstract: In this paper, we report our investigation effect of concentration of silver nanowires (AgNWs) solution on the AgNWs thin films coated onto a glass substrate by simple Meyer-rod coating. Diameter and length of AgNWs have used about 120 nm and 20 to 30 μm , respectively. Concentration of AgNWs were variated of 186 mg/ml, 210 mg/ml, and 223 mg/ml in ethanol solution. AgNWs thin films then were heated at temperature 90 $^{\circ}\text{C}$ for 20 min. The UV-vis spectrophotometry, scanning electron microscope (SEM), and four-point-probe were employed to characterize the AgNWs thin films. The result shows that concentration of AgNWs solution affects on the transmittance and a sheet resistance of the AgNWs thin films. The transmittance at the wavelength of 550 nm is obtained 94.5% by a sheet resistance about 1.2 Ω/sq . The higher concentration of AgNWs solution can decrease the sheet resistance and the transparency of the AgNWs thin films.

1. Introduction

Metal nanowire such as Ag Nanowires (AgNWs) generally drove from silver nitrate powder synthesized to produce nano-sized wire. Wich is about less than 100 nm with a length of 10 μm or more. Metal AgNWs synthesized in colloidal form, then deposited on a transparent substrate such as glass or plastic to create a random conductive mesh. AgNWs able to achieve high electrical conductivity when deposited at a temperature of about 200 $^{\circ}\text{C}$. AgNWs thin layers or films. A transparency value of AgNWs could reach 90 % and sheet resistance about 10 Ω/sq . AgNWs layer of high conductive and transparent is very suitable for transparent electrode applications [1-4].

Transparent conductive electrodes or transparent material can be produced using the fabrication method. Some of the methods used for fabricating AgNWs is spin coating, spray coating, dip coating, vacuum filtration, Langmuir-Blodgett (LB) assembly, and Meyer rod coating. But from some of the existing methods, the Meyer rod coating method has low production cost than the others [5, 6]. Vacuum filtration method produces highly transparent films with excellent conductivity, but the film has a significant roughness and irregular morphology. In addition, this process is not measurable. By using the drop-casting method shows discontinue film on the substrate. The film obtained from the water-spraying method is much better but still, form a network of rare and non-uniform. In short, most of the proposed process so far can't be easily produced on a large scale. In addition, research on the nature of the film and has a very limited effect factor. While the manufacture of transparent AgNWs film on plastic substrates by using Meyer rod through scalable, simple, and inexpensive to improve the performance of flexible electrodes [4, 7, 8].



Transparent electrodes were already fabricated on a substrate using a dry transfer technique [5,9,10]. For 12.5 mg/mL AgNWs solution silver nanowire was obtained with 10 Ω /sq of sheet resistance (R_s) and 85 % of optical transmittance. Kumar et al. also have studied the low-cost processing technique of fabrication to improve the optical and mechanical properties of transparent electrodes by controlling the ink composition, AgNWs ratio, and processing conditions. AgNWs with concentration 0.07 wt% showed high resistance which is upper of 1 K Ω /sq, but films with 0.15-0.9 wt% of AgNWs concentration showed low sheet resistance value and high transparency [11].

Properties of the fabricated thin film AgNWs affected by the concentration of AgNWs solution. However, most studies have only discussed the fabrication of thin film AgNWs without examining the solution effect and fabrication method towards properties of thin film AgNWs. Therefore, in this study we investigated properties of thin film AgNWs fabricated using Meyer rod coating method. Three different concentration of AgNWs is used for the fabrication using Meyer rod coating method.

2. Materials and Methods

2.1. Materials and Synthesis of AgNWs

Silver nitrate (AgNO_3), polyvinylpyrrolidone (PVP) with an average molecular weight 55000 g/mol, and copper (II) chloride dihydrate ($\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$) were purchased from Sigma–Aldrich, ethylene glycol (EG) was purchased from Bratachem, and ethanol. AgNWs were synthesized using a polyol method by some modifications [12,13]. Firstly, the amount of 50 ml EG solution of PVP (0.45 M) was heated at 150 °C and 140 μl $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ solution (0,1 M) injected into the flask after 5 min. The solution then stirred for 45 minutes and 130 °C. Next, 12 ml AgNO_3 solution of EG (0.5 M) were injected into the flask after one h. The reaction allowed at same condition further ± 2 h to complete the formation of AgNWs. AgNWs solution was washed and separated using ethanol by centrifugation at a speed of 6000 rpm for three times. Finally, AgNWs redispersed into ethanol solution.

2.2. Fabrication of AgNWs Thin Films

AgNWs thin films coated on the glass substrate (2.5 x 2.5 cm^2) by Meyer bar (RDS#4) purchased from R.D. AgNWs in ethanol solution with a concentration of 223 mg/ml, 210 mg/ml, and 186 mg/ml were sonicated for 2 min. AgNWs ink was injected using micropipette on a glass substrate and coated using Meyer bar. Afterward, the film was dried at 95 °C for 20 min using a hot plate and cooled to ambient temperature for next characterization.

2.3. Characterization of AgNWs

The optical transmittance of the thin film was recorded using Spectrometer UV-Visible (Shimadzu, UV-1700) in the wavelength range of 300 to 800 nm. The morphology of silver nanowires on film was determined by Scanning Electron Microscope (JEOL, JSM-650LA). The sheet resistance of the film was measured using a four-point probe technique with a Keithley 2401 source meter.

3. Results and Discussion

UV-Vis Spectroscopy characterization used to observe transmittance of thin film AgNWs. Figure 1 shows transmittance spectra of the 223.2 mg/ml, 210 mg/ml, and 186 mg/ml films coated by Meyer rod method. With increasing concentration, the samples showed a slightly yellowish color due to the increase in the AgNWs density. The films are highly transparent as the logo in the background can be clearly seen throughout the film. Figure 2 shows plots of the transmittance of the Meyer rod method as a function of the concentration of AgNWs solution. The values of transmittance used for corresponding to $\lambda = 550$ nm and the full transmittance spectra are shown in figure 2 for films with different concentration. The transmittance value at 550 nm of three different concentration of 186 mg/ml, 210 mg/ml, and 223.2 mg/ml films were found to be 97.25; 96.32; and 94.49 %, respectively. The transmittance of nanowire films increases with decreasing the concentration of AgNWs solution. The density of AgNWs is related to transparency of nanowire films where AgNWs density increases with

decreasing the concentration of AgNWs solution [14,15]. The value of transmittance and sheet resistance with different concentration of AgNWs solution can be seen in table 1.

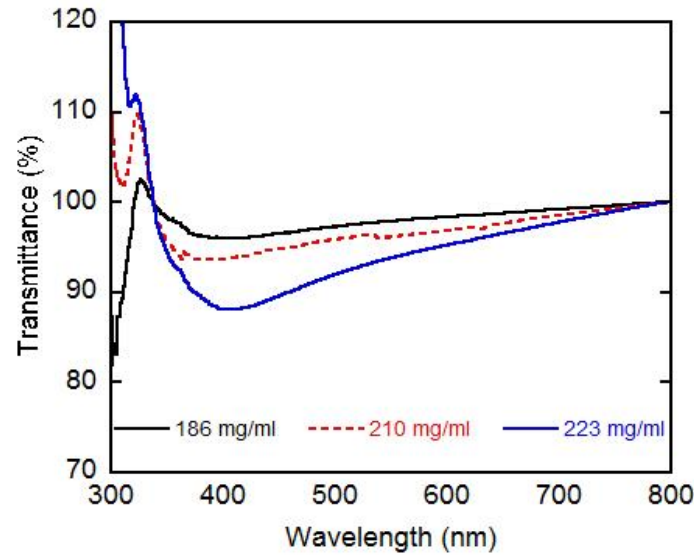


Figure 1. Transmittance spectra of AgNWs thin film

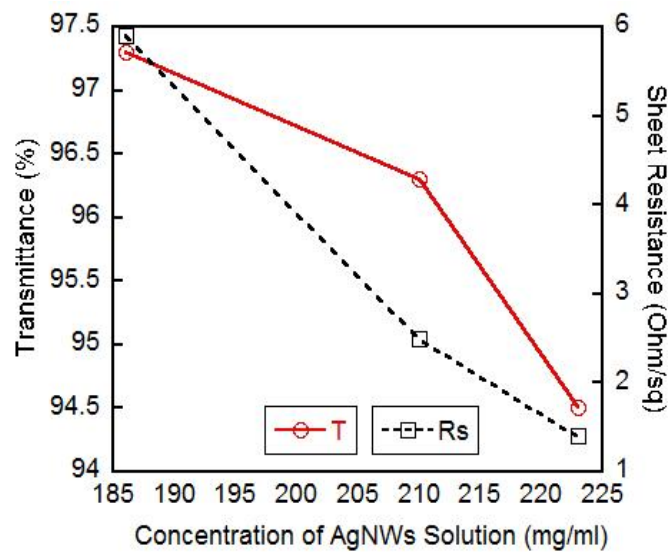


Figure 2. Transmittance and a sheet resistance of AgNWs thin films by different concentration of AgNWs solution.

Table 1. Optical and electrical parameters of different concentration of AgNWs solution coated film by Meyer rod method.

Concentration (mg/ml)	Transmittance (%)	Sheet Resistance (Ω /sq)
186	97.3	5.9
210	96.3	2.5
223	94.5	1.4

Four Point Probe used to measure the sheet resistance of AgNWs thin films coated by Meyer rod method with different concentration as shown in figure 2. The higher concentration of AgNWs solution can decrease the sheet resistance and the transparency of the AgNWs thin films. SEM analysis was used to observe morphology and distribution of wire on glass film as shown in figure 3.

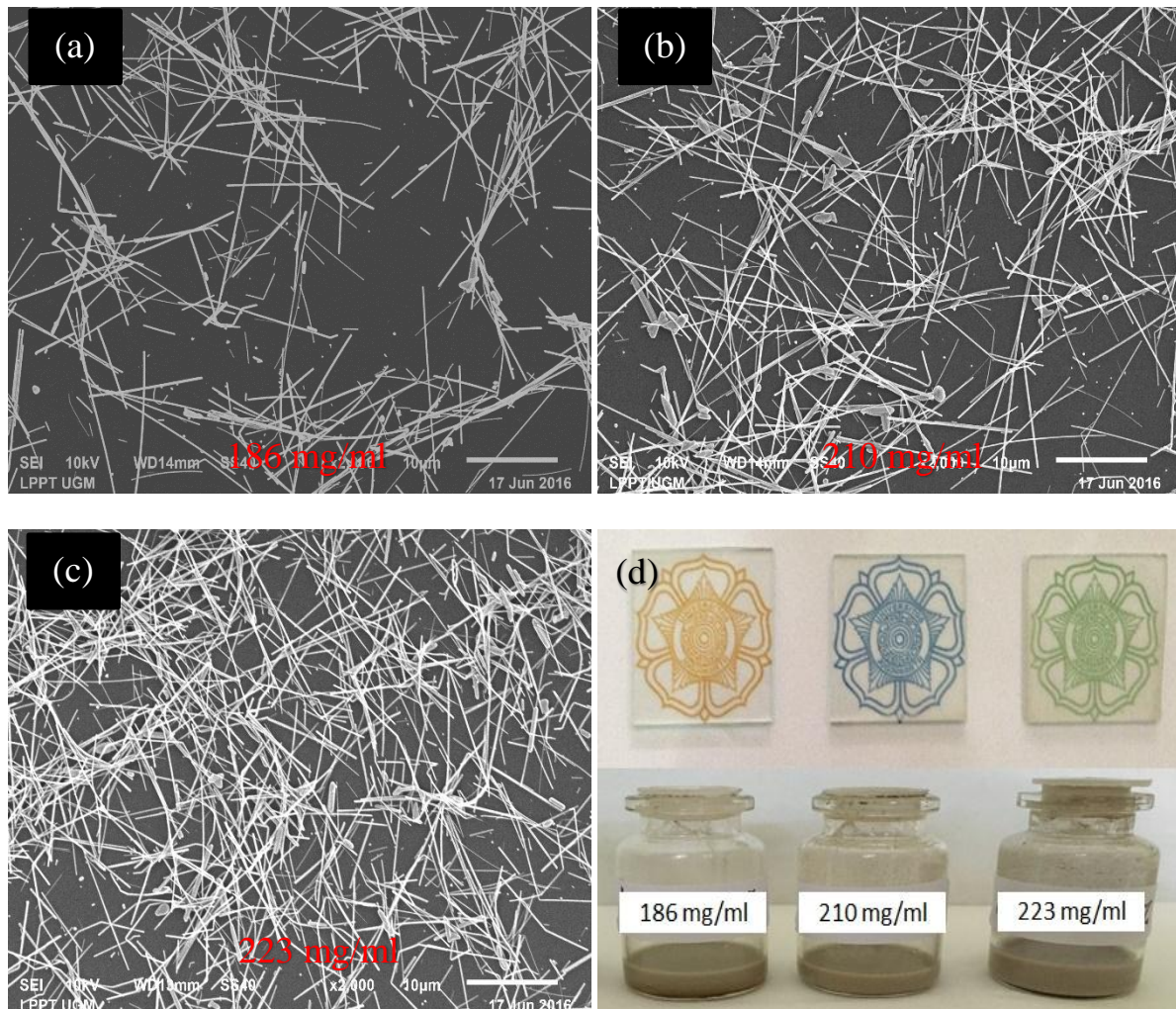


Figure 3. (a-c) SEM images of AgNWs thin films coated on a glass substrate using Meyer rod method and (d) AgNWs solution with various concentration.

Figure 3 shows that the distribution of Ag wire on substrate surface increases with increasing the concentration of AgNWs solution. The distribution of wires on the substrate depended on the concentration of the AgNWs solution. A substrate coated used a solution with a concentration of 223.2 mg/ml has more wire on the surface of the substrate than a substrate coated with a lower concentration. The diameter and length of silver nanowires before coating on the glass substrate and before using heating treatment are ~ 120 nm and 20 to 30 μm , respectively. When AgNWs coated on a glass substrate and heated at 95 $^{\circ}\text{C}$ length of silver nanowires decreased, this is because when AgNWs made into a solution with different concentrations, AgNWs was sonicated and heated resulting in the broken wire.

Conclusion

AgNWs solution coated on a glass substrate using Meyer rod method obtained by using 223 mg/ml concentration of AgNWs and highly transparent film. The transmittance of 94.5 % observed at a wavelength 550 nm which is the wavelength of visible light. The low sheet resistance of thin film AgNWs

using Meyer rod method is 1.4 Ω /sq. The higher concentration of AgNWs solution, decrease the sheet resistance and increased the transparency of the thin film.

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