Preparation and optoelectronic properties of silver nanowires

Lingkang Yuan, Daqiang Hu, Yichen He, Yunlong Huang*
(School of Science, University of Science and Technology Liaoning, Anshan 114051, China)

Abstract: In this paper, polyol method was used to prepare different silver nanowires solutions by changing the concentration of $FeCl_3{\cdot}6H_2O$ solution, and the solutions were spin-coated on conductive glass substrates to form silver nanowires films. The effect of the concentration of $FeCl_3{\cdot}6H_2O$ solution on the structure, surface morphology and optoelectronic properties of silver nanowires films were investigated. When 600 μM $FeCl_3{\cdot}6H_2O$ solution was added, the film had a high haze value of 0.099 at 550 nm and a low sheet resistance of 5.92 Ω/sq. The light trapping ability and electrical conductivity of silver nanowires films are improved.

Key words: Silver nanowires; Light trapping ability; Electrical conductivity

1. Introduction

Silver nanowires (Ag NWs), as one-dimensional metallic nanomaterials, have the characteristics of small size, high aspect ratio and large specific surface area. At the same time, Ag NWs have excellent optoelectronic properties, and the quality factor exceeds that of copper and other metal nanowires . Therefore, Ag NWs can be used in light emitting diodes, solar cells, liquid crystal displays and other optoelectronic devices, which have been widely concerned by researchers .

In recent years, researchers have carried out research work on Ag NWs-based transparent conductive films . Ag NWs-based transparent conductive films have attracted more and more attention due to their advantages of high transmittance, low resistivity and flexibility. At present, the main preparation methods of Ag NWs include hydrothermal method, electrochemical deposition method and polyol method. Among them, polyol method has the advantages of simple process, low preparation cost, uniform preparation of Ag NWs, good controllability and high purity .

In this paper, polyol method was used to prepare different Ag NWs solutions by changing the concentration of $FeCl_3{\cdot}6H_2O$ solution, and the solutions were spin-coated on conductive glass substrates to form Ag NWs films. The effect of $FeCl_3{\cdot}6H_2O$ solution with different concentrations on the structure, surface morphology and optoelectronic properties of the films were studied.

2. Experimental

2.1 Preparation

(1) Ag NWs were prepared by polyol method. Firstly, 0.53 g PVP and 0.41 g $AgNO_3$ were added to 40 ml ethylene glycol and stirred to dissolve. Then, the $FeCl_3{\cdot}6H_2O$ solution (0 μM, 300 μM, 600 μM, 900 μM in EG) was added. The mixed solution was injected into Teflon-lined autoclave, and then the autoclave was sealed and heated at 130 °C for 5 h. After the reaction was complete, the Ag NWs were centrifuged and washed with acetone and anhydrous ethanol respectively. Finally, the Ag NWs were dispersed in anhydrous ethanol.

(2) Ag NWs films were prepared by spin coating method. Firstly, the cleaned conductive glass substrate was placed on the coater, and the Ag NWs solution was evenly dispersed on the substrate. After spin coating (2500 rpm, 30 s), the films were annealed at 250℃ for 1 h under vacuum, and the Ag NWs films were finally obtained.

2.2 Characterization

The surface morphology of the samples was observed by NM900 optical microscope. The structure of the films was analyzed by X-ray diffractometer (XRD). The optical characteristics of the films were tested by UV-3600Plus UV-visible-near infrared spectrophotometer with an integrating sphere. The electrical properties of the films were measured by RTS-8 four-point probe at room temperature.

3. Results and discussion

3.1 Structural properties

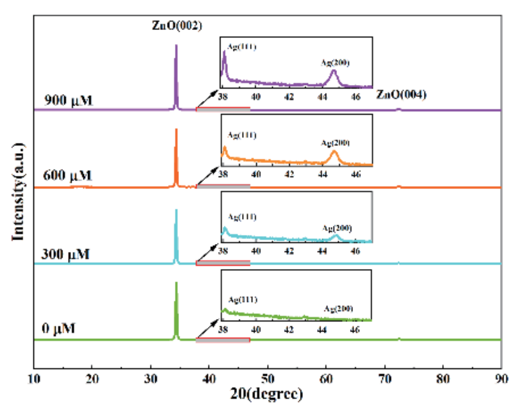
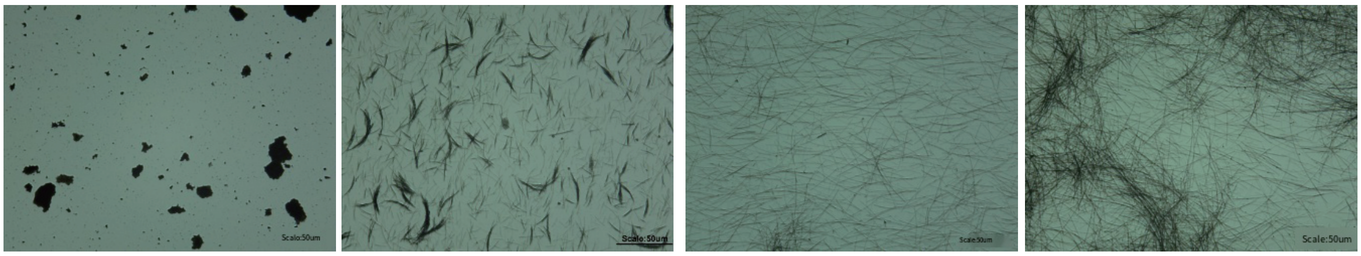


Fig. 1 XRD patterns of Ag NWs films prepared under different concentrations of $FeCl_3{\cdot}6H_2O$ solutions.

Fig. 1 is the XRD patterns of Ag NWs films prepared under different concentrations of $FeCl_3 \cdot 6H_2O$ solutions. In the same 2θ degree range, all Ag NWs films show a strong diffraction peak at about 34.4° and a weaker peak near 72.5°, corresponding to the (002) and (004) crystal plane of ZnO in the conductive glass substrates, respectively.

With the increase of the concentration of $FeCl_3 \cdot 6H_2O$ solution, it can be seen in the local amplification XRD pattern that two diffraction peaks gradually appear around 38.1° and 44.6°, corresponding to the (111) and (200) crystal plane of Ag, respectively. In addition, with the increase of $FeCl_3 \cdot 6H_2O$ solution concentration, the two diffraction peaks gradually increase in intensity. This is caused by the formation and length change of Ag NWs, which can be confirmed by the optical microscope images in Fig. 2.

3.2 Surface Morphology



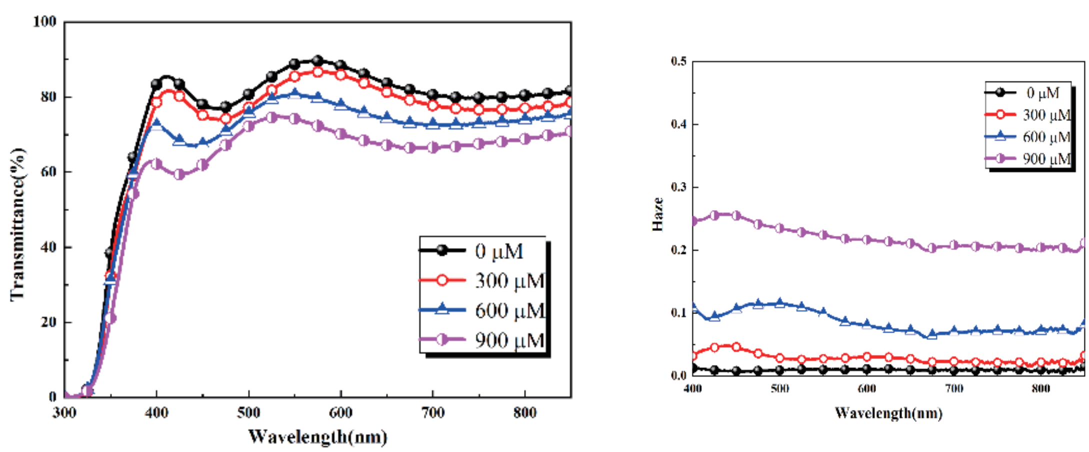
(a) 0 μM (b) 300 μM (c) 600 μM (d) 900 μM

Fig. 2 Surface optical microscope images of Ag NWs films prepared under different concentrations of $FeCl_3 \cdot 6H_2O$ solutions.

Fig. 2 (a), (b), (c) and (d) show the surface optical microscope images of Ag NWs films when $FeCl_3 \cdot 6H_2O$ solutions with concentrations of 0 μM, 300 μM, 600 μM and 900 μM are added, respectively. It can be seen that when $FeCl_3 \cdot 6H_2O$ solution is not added (0 μM), there are no Ag NWs, and only irregular large massive Ag particles are observed. When the concentration is increased to 300 μM, there are only shorter Ag NWs on the surface of the films. When the concentration is increased to 600 μM, Ag NWs with a certain length of about 30-50 μm are observed, and more Ag NWs are bonded to each other. This indicates that the higher concentration of $FeCl_3 \cdot 6H_2O$ solution is conducive to the formation of Ag NWs. When the concentration is increased to 900 μM, the length of Ag NWs is increased, and a large number of Ag NWs are densely bonded. It can be seen from the above results that with the increase of the concentration of $FeCl_3 \cdot 6H_2O$ solution, the Ag generated gradually is changed from nanoparticle shape to nanowire shape, and the length is gradually increased. And the Ag NWs are more fully bonded with each other, which corresponds to the increase of (111) and (200) peak intensities shown in the XRD results.

3.3 Optical properties

The influence of $FeCl_3 \cdot 6H_2O$ solution with different concentrations on the optical properties of Ag NWs films is studied by testing the total transmittance of the films, as shown in Fig. 3 (a). In the visible wavelength range (400 nm-800 nm), the average total transmittance of Ag NWs is 82.8%, 79.8%, 74.1% and 68.0%, respectively. With the increase of $FeCl_3 \cdot 6H_2O$ solution concentration, the average total transmittance of Ag NWs is decreased gradually, which may be caused by the increase of the length and bonding density of Ag NWs. Except for the Ag NWs prepared by adding 900 μM $FeCl_3 \cdot 6H_2O$ solution and removing the influence of glass substrate, the average total transmittance of other films is higher than 80%.



(a) (b)

Fig. 3. (a) Total transmittance spectra and (b) haze spectra of Ag NWs films prepared under different concentrations of $FeCl_3 \cdot 6H_2O$solutions.

The haze spectra of all Ag NWs films are measured, as shown in Fig. 3 (b). The haze value of Ag NWs films gradually increase with the increase of $FeCl_3 \cdot 6H_2O$ solution concentration. And the haze values are 0.010, 0.027, 0.099 and 0.224 at 550 nm, respectively. With the increase of FeCl3·6H2O solution concentration, the shape of Ag changes from nanoparticle to nanowire, and the length and the lap density of Ag NWs also increases gradually, which leads to the increase of light scattering and the corresponding increase of the haze value of the films. Although the film with 900 μM concentration has the highest haze value, its average total transmittance is lower than 80%. Therefore, Ag NWs films prepared at the concentration of $FeCl_3 \cdot 6H_2O$ solution of 600 μM have both excellent light transmittance and light trapping ability.

3.4 Electrical properties

As shown in Fig. 4, the sheet resistance of Ag NWs films prepared under different concentrations of $FeCl_3 \cdot 6H_2O$ solutions is measured. As shown in Fig.4, with the increase of concentration, the sheet resistances are 32.35Ω /sq, 33.46Ω /sq, 5.92Ω /sq and 2.41Ω /sq, respectively. Compared with the conductive glass substrate (32.10Ω /sq), the electrical properties of the films prepared by adding 0 μM and 300 μM $FeCl_3 \cdot 6H_2O$ solutions are not enhanced, because the Ag nanoparticles and short Ag nanowires on the substrate are not connected to form effective conductive networks. However, when the concentration of $FeCl_3 \cdot 6H_2O$ solution is increased to 600 μM and 900 μM, the sheet resistance is decreased significantly, which is due to the formation and length increase of Ag NWs. A large number of Ag NWs densely are bonded to form more conductive networks, and the electrical properties are greatly improved.

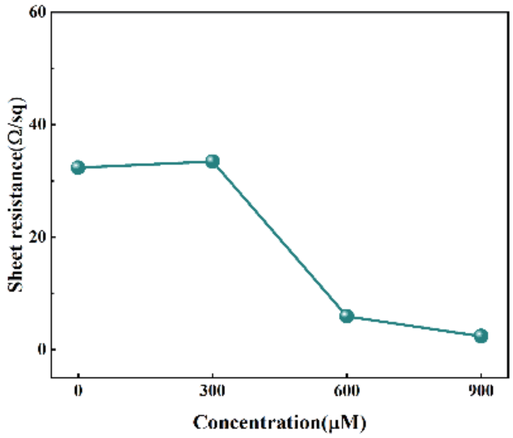


Fig. 4. Sheet resistance of Ag NWs films prepared with different concentrations of $FeCl_3 \cdot 6H_2O$ solutions.

4. Summary

In general, Ag NWs films with excellent optoelectronic properties were prepared by polyol method and spin coating method. The effect of $FeCl_3 \cdot 6H_2O$ solution with different concentrations on the structure, surface morphology and optoelectronic properties of Ag NWs films were studied. The results showed that the Ag NWs prepared with 600 μM $FeCl_3 \cdot 6H_2O$ solution had higher haze value (0.099 at 550 nm) and lower sheet resistance (5.92 Ω/sq). The obtained Ag NWs had better optoelectronic properties and light trapping abilities.

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* Corresponding author: Daqiang Hu

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