Investigation of heated silver nanowires under surface modification

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Abstract. Silver nanowires (Ag NWs) have received much attention and applied in many fields due to their excellent conductivity. Hence, Ag NWs were usually integrated with low conductive materials to enhance the conductivity of the overall system. In some conditions, the surface of Ag NWs need to be modified before combining with other materials. There are many ways to change and prepare the surface of Ag NWs, for example, ligand exchange which is a simple process. TOPO (trioctylphosphine oxide) is a robust coordinating ligand and is classified as an essential component for low-dimensional nanomaterials. In comparison, ODE (1-octadecene) is a noncoordinating ligand that is often used in quantum nanomaterials preparation. In this experiment, we investigated the surface attachment for ligand exchange of TOPO and ODE on the surface of Ag NWs under variations of reaction times at 150°C. The scanning electron microscope showed the rough surface when TOPO was added, and there was no noticeable change of surface when ODE was added. These results are promising for the preparation of heterostructure in the future.

1. Introduction
The study of one-dimensional (1D) material nanowire formations has gotten much attention because the integration of components impacts their performance in terms of electrical, optical, and thermal qualities. Silver (Ag) nanowires, in particular, were always chosen as the initial part for further combination with other materials such as ZnO, SiO\textsubscript{2}, TiO\textsubscript{2}, SnO\textsubscript{2}, Fe\textsubscript{3}O\textsubscript{4} due to their highly conductive and transparent qualities. [1-6] As a result, the surface modification with ligand exchange technique was used to prepare Ag nanowires for use. A ligand is an essential component in this process, especially strong coordinating ligands like TOPO (trioctylphosphine oxide) and weak coordinating ligands as ODE (1-octadecene). Both ligands were expected to be appropriate solvents for synthesizing low-dimensional materials. [7] In this experiment, we investigated the attached ligand of either TOPO or ODE and both of them on the surface of Ag NWs under variations of reaction times at temperature 150°C. The thickness and structure of the material were examined using a scanning electron microscope (SEM) and X-ray diffraction pattern (XRD). This method can be further used to create heterostructure for another application.
2. Experimental
2.1 Chemicals
Silver nanowire solution (4% W/W in IPA). Triocetyolphosphine oxide (TOPO, 99%) was purchased from Sigma-Aldrich and 1-Octadecene (ODE) (Technical grade 90%) was purchased from Alfa-Aesar, Toluene and Ethanol were purchased from Fisher. All of these were used without any further purification.

2.2 Experiment
For ligand attached on Ag NWs surface, TOPO 1.0 g (2.586 mmol) and ODE 15 mL were added to a round bottom flask under the presence of 0.3 mL of the as-prepared 4% W/W Ag NWs solution. The mixed solution was stirred under 620 rpm and heated to 100°C to remove impurities and isopropanol from the Ag NWs solution. After 30 min, the solution temperature was increased to 150°C under nitrogen gas. When the temperature reached this point, the reaction was cooked for 30 minutes. After that, the solution was cool down by immersing in a water bath for 5 min, and then it was centrifuged at 4,400 rpm followed by two times washing with toluene and ethanol to remove excess TOPO and storing in toluene.

3. Results and discussion
As-prepared Ag nanowires synthesized by polyol method with smooth surface and uniform were characterized by scanning electron microscope (SEM) as shown in figure 1. Diameter of NWs approximately 90 ± 8 nm with 8.7 µm in length.

![Figure 1](image-url)

**Figure 1.** SEM images of as-prepared silver nanowires with a) 20kx and b) 60kx magnification.

Following that, Ag nanowires surface were modified with either TOPO or ODE solvent at 150°C for 5 min. Figure 2a depicts the rough surfaces of TOPO, whereas Figure 2b depicts the smooth surfaces of ODE solvent. The average diameter of modified Ag NWs in TOPO is 88.70 nm, whereas it is 87.12 nm in ODE. It means that TOPO can attach to the surface of Ag nanowires and no ODE on the surface of Ag nanowires.
Figure 2. SEM images and diameter of modified Ag nanowires surface under 150°C with: a) TOPO and b) ODE solvent.

Under a combined TOPO and ODE solvent with a cooking temperature of 150°C for 5 min, the rough surface from TOPO is also apparent. The result is obtained with a larger diameter at 91.21 nm (Figure 3a). When the reaction time increased to 30 min, the rough surface still appeared, and the diameter of modified Ag NWs surface gradually increased to 93.76 nm, as seen in Figure 3b. The increasing diameter depicted the thickness of modified Ag NWs as a function of reaction time.

Figure 3. SEM images and diameter of Ag nanowires with co-operating TOPO and ODE solvent under 150°C with reaction time: a) 5 and b) 30 min.
Finally, the XRD pattern was used to analyze the surface-modified Ag NWs structure. The XRD pattern exhibits peaks of bare Ag NWs and surface-modified Ag NWs at different conditions, as shown in Figure 4. The four peak positions correspond to the FCC structure: (111), (200), (220), and (311). The XRD pattern revealed that the structure of Ag NWs was not damaged and unchanged during the modification process.

4. Conclusions
The surface modification of Ag nanowires in our experiment proposed ligand exchange with TOPO or ODE under 150°C. TOPO can attach to the surface of Ag nanowire, while ODE has no effect. Furthermore, when TOPO and ODE are mixed with increasing the reaction time, the results show a thicker rough surface in SEM image with gradually increasing diameter without deformation of Ag nanowires structure. Therefore, these results are promising for the preparation of integration of Ag nanowires with other materials in the future.

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