

A New Wet Chemical Approach for the Selective Synthesis of Silver Nanowires

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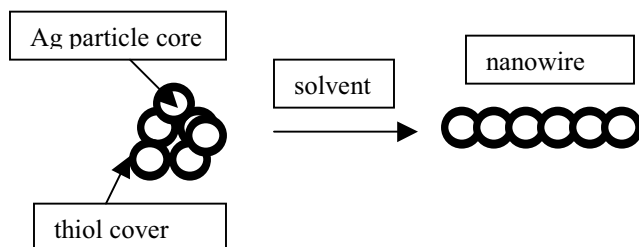
ABSTRACT

A new wet chemical approach is presented for the selective synthesis of silver nanowires based on the assembly of silver nanoparticles covered with a bi-functional thiol. The particles are formed spontaneously upon the addition of trace amounts of the thiol to silver nitrate. Dilution of the particle with water leads to the formation of a clear dispersion of white flakes. The silver nanowires are formed while drying the flakes in air. The silver nanowires are characterized with scanning electron microscopy (SEM) and have aspect ratios of about 46. The results are discussed in the context of an assembly mechanism driven by intermolecular interactions among thiol molecules.

Keywords: silver nanowires, silver nanoparticles, assembly of particles into wires, nanowires SEM

1 INTRODUCTION

There is tremendous interest in the synthesis of silver nanowires due to the important role they are to play in the manufacture of electronic devices. Long aspect ratio silver nanowires may find applications in nanoscaled electrical circuits requiring long electrical connections. Wires with short aspect ratios find applications relevant to the wireless telecommunication industries. Here we report on a simple, wet chemical approach to the selective synthesis of silver nanowires of varied aspect ratios. The method is based in the assembly of silver nanoparticles using a bi-functional alkyl thiol, as illustrated in scheme 1.



Scheme 1: assembly of silver nanoparticles into nanowires.

2 EXPERIMENTAL

The silver nanoparticles are prepared in a glass reactor. The reactor has a cylindrical shape and is 5 cm long and 1 cm in diameter. Scanning electron microscopy measurements were performed in a JEOL 6460 HV/LV instrument. Fourier transform infrared (FTIR) measurements reported here were performed in a Matheson FTIR instrument coupled to an Olympus microscope. All FTIR microscopy measurements reported here were performed in the surface reflection mode with an aluminum coated objective and with a times thirty (30 x) magnification. UV absorption measurements were performed with a deuterium lamp with an Ocean Optics 2000 spectrograph.

3 RESULTS

3.1 Synthesis of thiol-silver material

A yellow material is spontaneously formed upon the addition of a few μL of thiol to 2 mg of silver nitrate. The yellow material is then diluted with 10 mL of water and the reactor is closed. A bright yellow solution is immediately

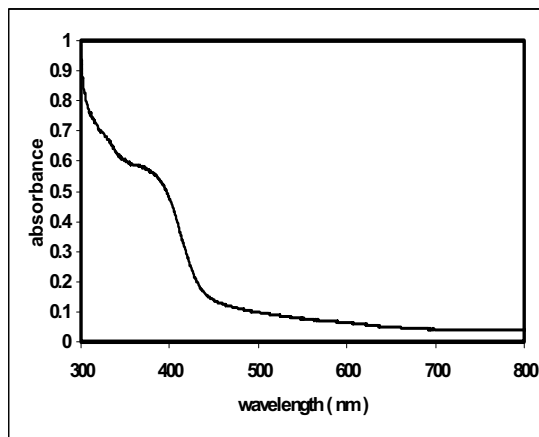


Figure 1: UV-visible absorption spectrum of a thiol-silver material diluted with 10 mL of solvent.

formed. The yellow solution turns to a bright green color a few seconds after the mixture is prepared. A clear dispersion of white flakes forms a few minutes after the formation of the green solution. The dispersion was stored in the dark to avoid the breakdown of the thiol and release of silver nanoparticles into the aqueous solution.

A typical UV-visible absorption measurement of the dispersion, prepared as described above, is displayed on figure 1. A band centered at 388 nm is the only peak observed in UV-visible absorption measurements. This band is typically found in silver nanoparticles a few nanometers in size. The lack of bands due to the transverse and longitudinal plasmon modes indicates that no other silver nanostructures, like nanowires or nanorods, are formed at this point in the synthesis process.

3.2 Synthesis of silver nanowires

A representative SEM image on a deposit from the solutions described above is displayed on figures 2a and 2 b. The deposit was allowed to dry in the dark for over 24 hours prior to the insertion in the SEM chamber. Silver

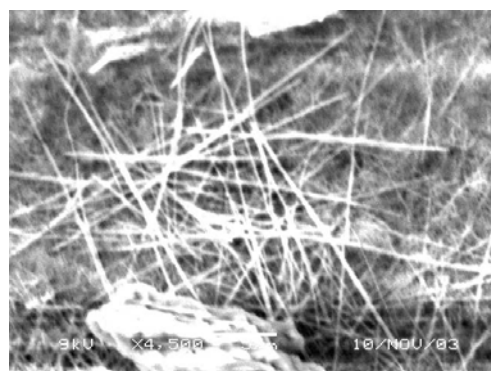
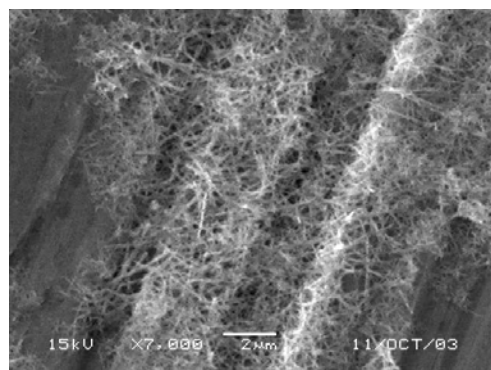


Figure 2: SEM images of two different regions of deposits of thiol-silver materials diluted with 10.0 mL of solvent.

nanowires are the only nanostructures observed. Evidence for the formation of silver nanospheres or rods was searched for, but not found. The wires displayed on figure 2b are (12 ± 3) nm in diameter and (260 ± 40) nm in diameter and have an average aspect ratio of 46. Significantly, not a single particle is observed in SEM images of these deposits, indicating that the method is very selective for the synthesis of nanowires.

3.3 Mechanism of silver nanowires synthesis

A representative SEM image on deposits of the thiol-silver deposit following the addition of a trace amount of solvent is displayed on figure 3. The SEM image is characterized by a large number of agglomerates of particles. The agglomerates range from 10 to 1 micrometer in size. The particles forming the agglomerates are about (300 ± 100) nm in diameter.

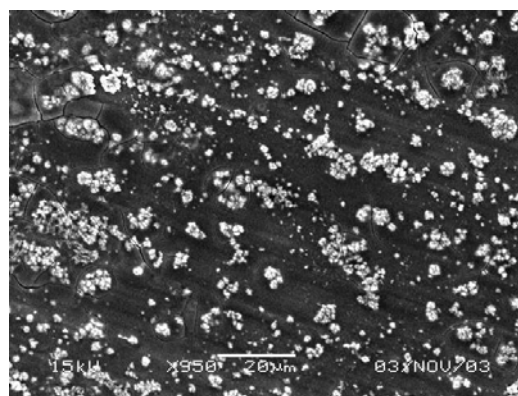


Figure 3: SEM image of deposit of silver-thiol material wetted with a trace amount of solvent.

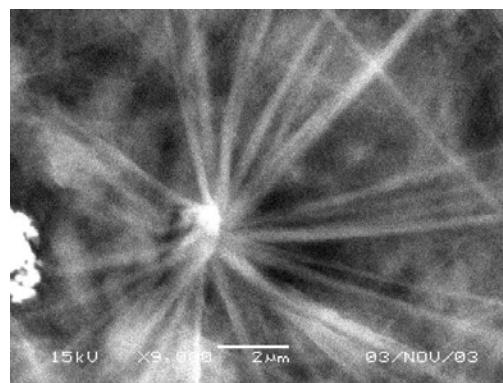


Figure 4: SEM image of a silver-thiol material following the addition of 500 µL of solvent.

Silver nanowires emerge from these agglomerates upon the addition of larger amounts of solvent, as illustrated in the SEM image displayed in figure 4. The wires are about 200 nm in diameter and do not have any specific orientation. Taken together, the SEM images presented in figures 3 and 4, are consistent with the assembly of the silver nanoparticles into wires assisted by the solvent.

4 DISCUSSION

Silver nanoparticles are formed from the reduction of silver cations with mercapto acetic acid. This conclusion is supported by the observation of the 390 nm band in the UV-visible absorption measurements of dispersions prepared by diluting the pastes with water. The observation of particles in the SEM measurements performed on fresh silver-thiol materials is consistent with this conclusion. Furthermore, the SEM measurements on deposits prepared from the addition of trace amounts of water to these materials provide further support to this conclusion. Particle and particle agglomerates are formed upon the addition of 100 μ L of water to the paste. Silver nanowires are formed when pastes are mixed with larger amounts of water. The lack of absorption bands due to the longitudinal and transverse plasmon modes in UV-absorption measurements of silver-thiol materials diluted with water indicates that the wires are formed while drying the deposits. The observations listed above lead us to conclude that the nanowires form from the assembly of silver nanoparticles, as illustrated in scheme 1. The assembly of particles into wires is mediated by the thiol, as no wires are observed in a typical silver nitrate reduction. Water plays a central role in the synthesis of the silver nanowires described here. Water partially removes the thiol from the particles, similar to its role in the preparation of photo resists and masks. The partial removal of thiol and sulfur oxides from the particle surface facilitates the combination of particles and the formation of wires.

5 ACKNOWLEDGEMENT

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