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Synthesis of Silver Nanowires for Conductive Ink

Ryan Michael Huard
University of New Hampshire - Main Campus

Derek James Hellested
University of New Hampshire - Main Campus

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Ryan Huard, Derek Hellested
Department of Chemical Engineering
University of New Hampshire, Durham, NH

Background

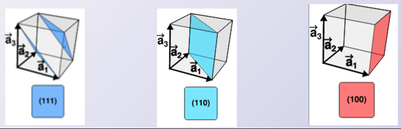
Conductive ink is used in various technologies, such as solar panel current collectors. The purpose is to create ink with a low resistance, allowing for the a higher collection of solar radiation to increase efficiency.

Typical inks contain solvent, binder, silver powder, and rheological agents. The binder is useful in dispersing silver powder into the solution to form smooth, homogeneous ink.[1]

Research groups at the University of New Hampshire Chemical Engineering Department and Conductive Compounds LLC in Hudson, NH are working together on this project with support from the NSF under Grant #CMMI-1200544

Nanowire Synthesis

- Two stages: Nucleation and Crystal Growth
- Start synthesis by forming silver nuclei
- Reach the critical nucleus size
- Particles continue to grow from the critical nuclei
- Growth is limited by diffusion
- Ethylene glycol (EG) is used as a precursor reducing agent and solvent
- Silver Nitrate ($AgNO_3$) is used as the source for silver.
- Copper (II) Chloride ($CuCl_2$) is added to scavenge oxygen
- Polyvinylpyrrolidone (PVP) adsorbs faces of silver to inhibit growth in 2 directions (perpendicular to face, 100)[3], resulting in 1D growth

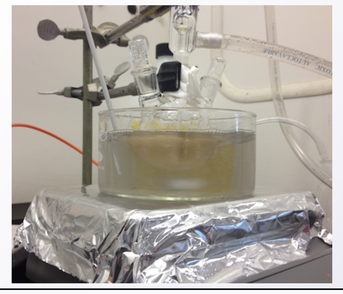


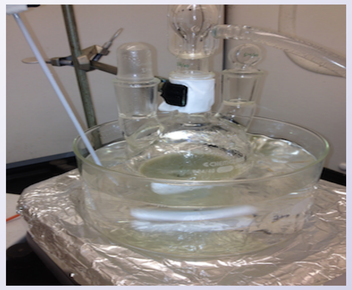
Objectives

- Synthesis of silver nanowires (AgNW)
- Reactor scale up to ten times the bench scale
- Collect rheological data under screen printing conditions
- Ink formulation to minimize electrical resistance and optimize printing performance

Reactor Design

- Nanowire synthesis under inert atmosphere with rapid magnetic stirring
- Successive scale up design
- Challenges of scale up include good mixing and clean injection
- 3 times (right) and 10 times (left) than original bench scale

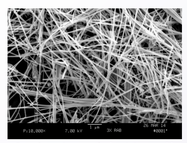


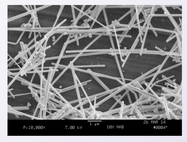


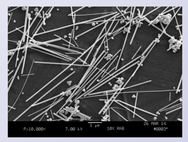
Particle Characterization

- Smaller reactor scales have higher yield of cylindrical particles
- More spherical particles present without needle injection of argon
- Gas atmosphere in reactor influences particle shape[1]

SEM Imaging of particles from various experiments


3x in Ar with Needle


10x in Ar with Needle


10x in Ar

Reaction Mechanisms

The reaction below shows the formation of silver nanowires

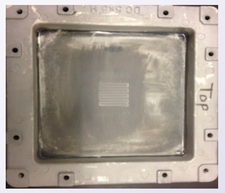
$$Ag^{+}_{(aq)} + R \rightarrow Ag_{(s)} + O$$

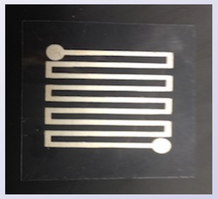
The R represents a reduced form of EG. The O represents the oxidized EG agent. The $Ag_{(aq)}$ is provided by $AgNO_3$.

Cu(II), added as $CuCl_2$ is reduced by EG to Cu(I). Cu(I) is then oxidized by oxygen back to the Cu(II) state. The reaction with oxygen removes dissolved O_2 from the solution. O_2 is a poison for the crystal growth.

Screen Printing

- Commercial application of conductive ink with AgNW
- Print test circuits using commercial ink and compare results to synthesized ink
- Print onto silicon chips and test resistance





Current Results

- Synthesized silver nanowires
- Scaled up reactor 10 times the original quantity
- Synthesized silver nanowires with dimensions 25nm in diameter with a 230nm length
- 111 orientation of nanowire determined by x-ray diffraction

Future Research

- Study rheological properties of conductive inks
- Determine if wire orientation of nanowires in ink can be controlled
- Investigate production of 100 nanowire orientation
- Investigate synthesis of longer nanowires

References

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