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Microwave Synthesis of Oxidation-Resistant Copper Nanoparticles for Additive Manufacturing Applications

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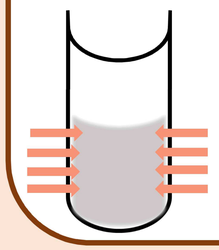
Copper is a Viable Option for Electronics

Materials that are cost effective and environmentally sustainable are highly desired for 3D printed electronic components including resistors, transistors, transformers, and capacitors. Through additive manufacturing, copper nanoparticles can be applied in the production of electronic components. However, copper has multiple downsides, including its susceptibility to corrosion and oxidation. Finding a green synthetic route that will inhibit oxidation of copper nanoparticles is crucial to gaining traction for its use in the future.

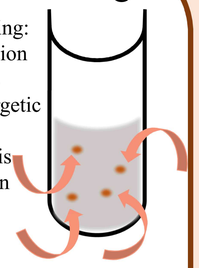
Images of circuits that could potentially be printed

Advantages of Microwave Heating

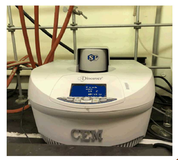
Conventional Heating:
- Superficial/wall heating
- Slow synthesis
- Inaccurate temperatures
- Less dependent



Microwave Heating:
- Direct interaction with materials
- Promotes energetic coupling
- Rapid synthesis
- Milder reaction conditions



The microwave used for all synthetic reactions was the CEM Discover Microwave



Generating Oxidation-Resistant Cu NPs

Precursor → **Solvent** → **Surfactant** → **Environment Testing** → **Printing**

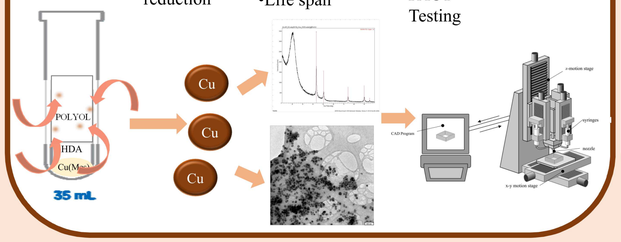
Cu(Mes)
- Environmentally friendly
- Easily decomposable

Polyols
- Couples well with MW
- Increases reduction

Hexadecylamine
Influence on surface of Cu NP
- Oxidation
- Agglomeration
- Life span

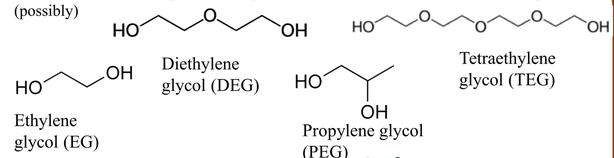
Inert vs Ambient
- PXRD
- FTIR
- TEM
- XPS
- FACT-Testing

3-D Printing
- Ink-jet printing
- aerosol

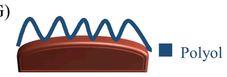


Understanding the Role of the Surfactant

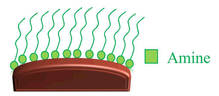
Polyols (solvent) – Inexpensive, couples very well with microwave, and surface protector (possibly)



SQ: How does the ethylene group play a role in the production and protection of Cu-NPs?



Amines – inexpensive, couples with metallic NPs surface, and long protective chains



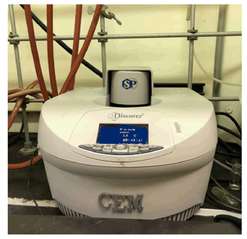
Surfactant

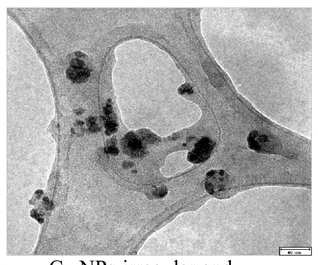
$CH_3(CH_2)_{14}CH_2NH_2$
Hexadecylamine (HDA)

SQ: How does the surfactant effect the oxidation, agglomeration, …etc behavior of the Cu-NPs?

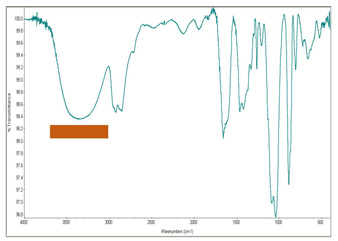
Cu-NPs from Cu(Mes) in Ethylene Glycol (EG)

Procedure/Materials:
1) Add 1 g of Cu(Mes) to vial
2) Add 20 mL of polyol solvent
3) Add 3 g hexadecylamine (HDA) *for polyol+HDA study
4) Microwaved to 150 °C for 5 minutes



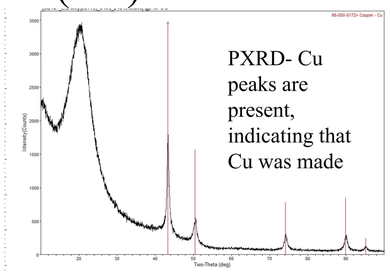


Cu NPs-irregular and undefined shape and size

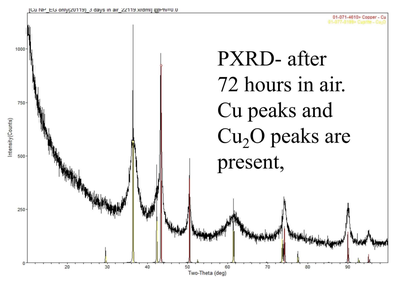


FTIR - O-H from 3200-3600 cm^{-1}, indicating that the polyol is on the surface of the Cu NP

Inert – 72 hours in air



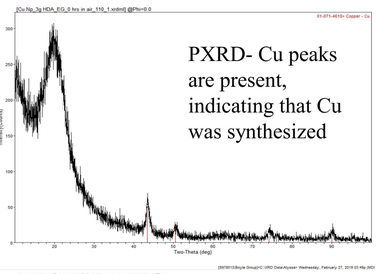
PXRD- Cu peaks are present, indicating that Cu was made



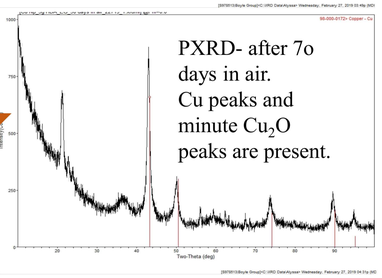
PXRD- after 72 hours in air. Cu peaks and Cu_2O peaks are present,

Cu-NPs from Cu(Mes) in (various polyol + HDA)

Inert – 70 days in air

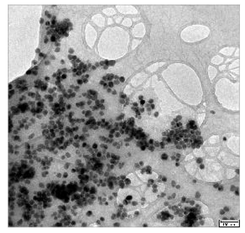


PXRD- Cu peaks are present, indicating that Cu was synthesized

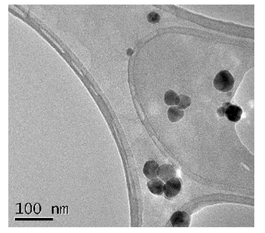


PXRD- after 7o days in air. Cu peaks and minute Cu_2O peaks are present.

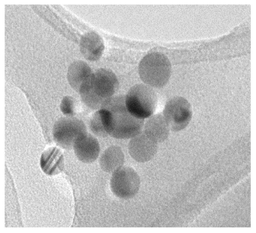
EG+HDA -spherical shape with an average size of 10 nm



DEG+HDA -spherical shape with an average size of 30 nm



PEG+HDA - spherical shape with an average size of 40 nm

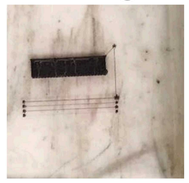


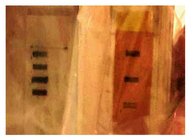
Size of the NPs is dependent on the polyol

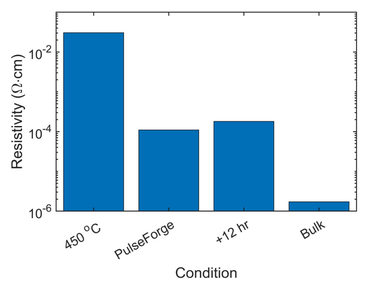
Additive Manufacturing Initial Efforts using Cu NPs

Goal:
- Produce a printable ink that is conductive and homogenous
- Aerosol jet print patterns for testing
- Test the printed materials in various Environmental conditions

Methods Used:
- Various solvents (polar)
  - Differing ratios and total volumes
- Varying weight % of Cu NP
- Using Cu NP synthesized with only solvent and solvent + HDA







Summary

- An easy scalable/green microwave synthesis for oxidative resistant copper nanoparticle was developed
  - Efforts to optimize and understand the mechanism are in progress
- Printing efforts have yielded conductive copper traces
  - Recipes and process parameters need to be optimized
- Future work will test the NPs and printed materials in various environmental conditions

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