Bottom-Up Synthesis of Nickel and Copper Nanoparticle Ink for Aerosol Jet Printing

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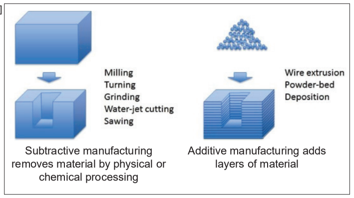
Introduction



[1]

- Additive manufacturing utilizes metal nanoparticle ink for the printing of microelectronic devices.
- Since this technology is in its infancy, only a few metal nanoparticle inks are commercially available.
- Nickel and copper nanoparticle inks were developed and will be printed using an Optomec-200 Aerosol Jet Printer.
- Surface Acoustic Wave (SAW) devices will be printed on a piezoelectric substrate to show the viability of the nanoparticle ink.
- The devices are to be characterized, optimized, and utilized in the pursuit of high temperature sensors that can withstand neutron bombardment.

Objectives

Synthesize metal nanoparticles → Make an ink out of the nanoparticles → Print the ink using an Aerosol Jet Printer → Test printed sensors for viability

Methods

Metal salt —(1. Ethylene Gylcol; 2. Polymer capping agent; 3. Δ; 4. Reducing agent)→ Polymer capped metal nanoparticles

- Focused on nickel(II) acetate and copper(II) sulfate
- Use of the **Polyol Method** for nanoparticle synthesis. [2]
- Nanoparticles were capped with polyvinylpyrrolidone (PVP) and reduced using sodium borohydride ($NaBH_4$) [3]
- Nanoparticles were isolated from ethylene glycol using an ultra-centrifuge set at 28k rpm.
- Then they were washed two-three times with ethanol to remove any remaining organic material

Results

- The nickel nanoparticles were made into an ink and printed with an Aerosol Jet Printer.
- The ink was a mixture of nickel nanoparticles, ethylene glycol, water, and glycerol. [4]
- The printed line widths were between 20um and 100um.
- A simulated print of the inter-digitated transducers (IDT) was conducted.
- Copper nanoparticles were synthesized according to the same synthesis procedure as the nickel nanoparticles.

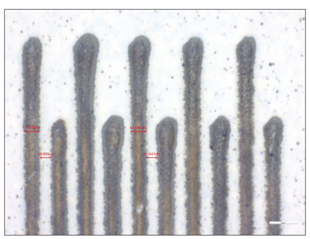
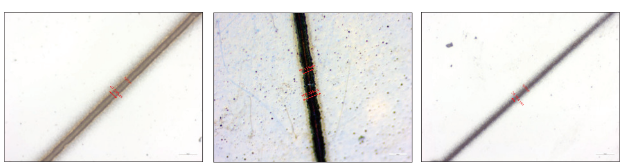


Figure 1: Image of a printed SAW device with lines of nickel nanoparticle ink 60-65um wide and spaces 40-45um wide

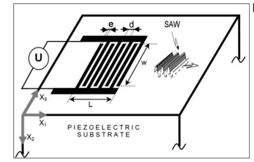


Figures 2-4: Lines of nickel nanoparticle ink printed by an Aerosol Jet Printer ranging from 25um to 60um in width

Expanding the inventory of **metallic nanoparticle inks** advances the field of **additive manufacturing** of microelectronics

SEM image of nickel nanoparticle agglomerates taken by Alexis Quick

SAW Devices

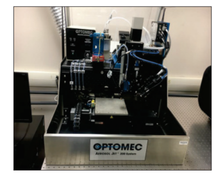


[5]

- Inter-digitated transducers are printed on a piezoelectric substrate [6]
- An oscillating voltage is applied to the device to produce surface acoustic wave
- The piezoelectric substrate propagates longitudinal waves across the surface

Surface Acoustic Waves (SAW) are sound waves that travel parallel to the surface of the substrate. They are preferred for applications involving indirect contact or high-temperature measurements. **Piezoelectric effect** is the ability of a material to generate an electric charge in response to applied mechanical stress. Piezoelectric sensors have a simple structure, fast response time in high-temperatures, and are easy to integrate into any system.[7]

Aerosol Jet Printer



Advantages:
- Maskless (Direct Transfer)
- Efficient
- Cost-effective

Disadvantages
- Underdeveloped technique
- Few commercially available inks

Characterization

TEM, DLS, and XRD

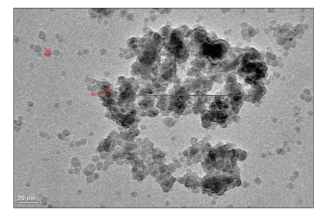


Figure 5: Transmission Electron Microscopy image of nickel nanoparticle ink featuring a 150nm agglomerate and individual 5-10nm particles

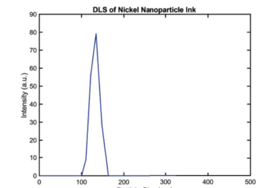


Figure 6: Dynamic Light Scattering data for nickel nanoparticle ink showing the average agglomeration size is about 140nm

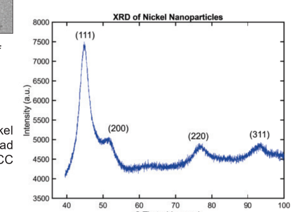


Figure 7: X-ray Diffraction pattern for nickel nanoparticles that confirmed the particles had no contamination and a crystal structure of FCC

Future Work

Making an ink out of the synthesized copper nanoparticles → Optimizing the ink components for both metals → Optimizing the printing of both metal inks → Testing the printed SAW devices for high temperature applications.

References:
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Acknowledgements:
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