Synthesis of Cu Nanoparticles Using a Micro-Mixer
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Opportunities
• Copper (Cu) nanoparticles are a possible substitute for noble metals in inkjet printing applications
• The nanoparticles’ properties can possibly lead to inkjet printing of circuit networks
• Local startup MicroflowCVO seeks to produce mono-dispersed Cu particles for wide range of applications

Objectives
• Compare the Y-mixers to the micro-mixers
• Characterize the micro-mixer’s effect on particle size distribution
• Characterize the effect of particle size on melting temperature

Background
Bulk copper vs. copper nanoparticle
• Bulk copper melts at 1085 °C
• Cu nanoparticles melts ~ 300 °C
• High surface to volume ratio
• High surface energy
• Melting temperature decreases with particle size

Nucleation: A thermodynamic approach
Diffusion limited growth
Fick’s First Law
\[ J = \frac{4\pi D (r + d)}{d} (C_a - C_f) \]
Surface Flux
\[ J = \frac{4\pi k (C_a - C_f)}{d} \]

Experimental setup
1. Reactants are pumped at 2.5 mL/min each
2. Reactants are mixed under different mixers
3. Nucleation and growth occur under residence time unit
4. Solution is chilled in ice bath to halt further reaction
5. Final solution is centrifuged and suspended in EtOH

Characterization
SEM/EDX is used to analyze particle size, morphology, and distribution.
DSC/TGA along with mass spectrometry is used to determine thermodynamic properties and sample composition.

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Materials and Method
MicroflowCVO micro-mixer
• The purpose of MicroflowCVO’s micro-mixer is to achieve efficient mixing by channeling fluids into intersecting paths that induce cross flow.
• Cross flow’s chaotic behavior is an efficient way to mix laminar flow streams.
• The micro channels increase the fluid-fluid interfaces resulting in a higher net diffusion flux and further mixing.
• The mixer three dimensional design is separated into multiple micrometer slices which are stacked to create a maze of channels that intersect and induce cross flow.

Design of Experiment (DOE)
• 8 factors DOE
• Type of mixers [Y-mixer, Micro-mixer]
• Residence time unit length [30 cm, 60 cm]
• Heating bath temperature [95°C, 115°C]

Results
Figure 1: Comparison of SEM images for Cu particles for (top) micro-mixer and (bottom) Y-mixer samples. There are large particles along with nanoparticles for the Y-mixer product. This is due to inferior mixing of the Swagelok Y-mixer.

Figure 2: (Left) Size distribution of copper nanoparticle (n=40) for lower temperature (T <100 °C) sample with 6 seconds residence time. The result proves that MicroflowCVO micro-mixer provides a narrow distribution. (Right) The high temperature sample with 42 seconds residence time showed that micro-mixer has control on the particle sizes. Both results show improvements due to enhanced mixing.

Figure 3: (Left) An example of typical DSC curve for melting temperature analysis. (Right) Melting temperature versus particle diameter.

Figure 4: EDX results that (left) verified the copper particles after synthesizing process and (right) showed oxidation in the residual of DSC experiment.