Ink formulation for SIJ in Extreme Environments

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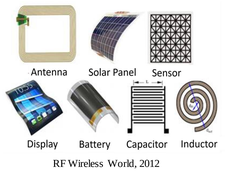
I. Introduction

Goal: Development of nanoparticle based-inks compatible with Super Ink Jet Printer for extreme environments

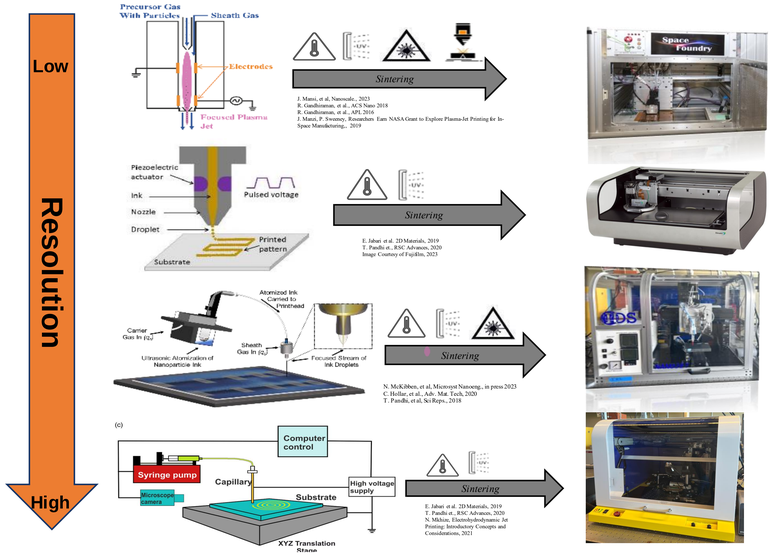
Printed electronics are important for several reasons.

- Enables the fabrication of flexible and lightweight electronic devices
- Offers cost-effective manufacturing processes
- Allows for large-scale production and potential integration into various industries such as consumer electronics, energy, and healthcare.
- Wearable biosensors and Internet of Things (IoT) shown great potential in healthcare and environmental monitoring offering suitable, low-cost, portable instruments for detecting infections, proteins, and other analytes quickly.[1]



SIJ Advantages[2]	SIJ Disadvantages[2]
• Noncontact patterning technique thus safe to use for multilayer processes	• Prone to nozzle clogging
• Variety of materials processable	• Glass tips are easily broken
• Does not require vacuum	• Resolution limited by nozzle diameter
• Highly reproducible	• Unable to process materials with high viscosity
• No substrate modification required to achieve high resolution	• High initial setup cost

Printer	Spatial Resolution	3D Printing (Y/N)	Particle Size	Viscosity (cP)	Solvents	Commercially Available Inks
IJP[3,4,5]	18 µm	No	50-200 nm	<16	MEK	Primera LX900 / RX900 53428, Afinia L501 / Afinia L502,
SIJ[2,6,7,8]	≤50 nm	Yes	140 - 1517nm	1-1000	Polar Solvents (water, ethanol)	Ag
AJP[9,10,11]	<20 µm	Yes	<200 nm preferred (300-500 nm max)	1-1000	Ethylene-glycol, water, Polyimide, Polyurethane	Au, Pt, Ag, Ni, Al, C
PJP[12,13,14]	~10 µm->1µm	Yes	40-60 µm	1-5	Polar Solvents (PVAL)	Ag, Pt, Ti3C2



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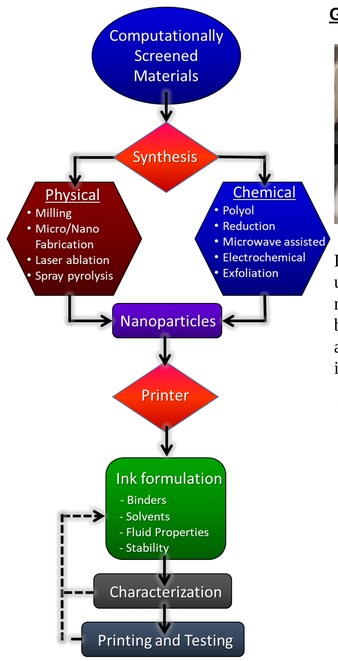
II. Materials and Methods



Gold Nanoparticle Synthesis:

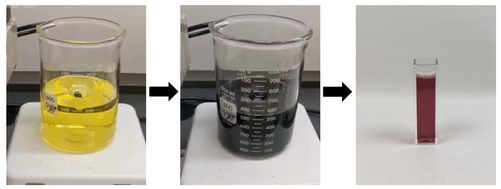
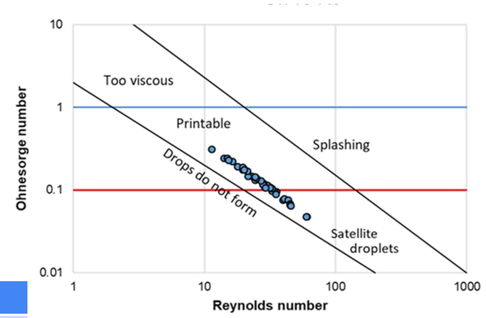


Figure #:1 Synthesis of gold nanoparticles. The gold is synthesized using sodium tetrachloroaurate as the gold precursor and reduced to metal gold nanoparticles by dropwise addition of sodium borohydride. After synthesis, the solvent is replaced with pure water and the gold nanoparticles are concentrated to formulate a printable ink.

Rheology:



Characterization Techniques:
• TEM (Transmission electron microscopy)
• Tensiometer
• SEM (Scanning Electron Microscope)
• TGA (Thermogravimetric Analyzer)
• DLS (Dynamic light scattering)

Equations:

Ohnsorge Number $Oh = \frac{\mu_g}{\sqrt{\sigma \rho d n}}$

Reynold's Number $Re = \frac{q_g \rho_g}{\pi r_n^2 \mu_g} d_n$

Focusing Ratio $F_R = \frac{q_s}{q_c}$

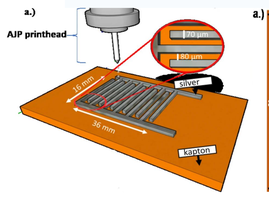
Total Gas Flow $q_g = q_s + q_c$

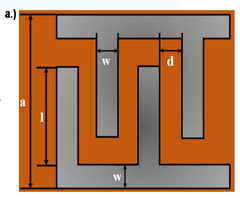
Impinging Jet Velocity $v = \frac{q_g}{\pi r_n^2}$

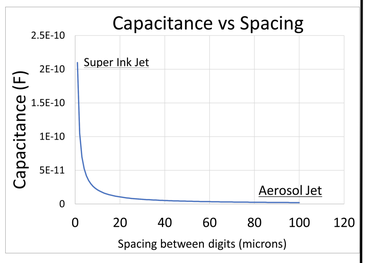
Gold nanoparticle synthesis[15]:

- Room temperature wet chemical reduction.
- 2g of HAuCl4 .3H2O in 2L of nano-pure water
- 4g of dissolved PVP
- Drop wise addition of NaBH4
- Formed PVP capped Au NP
- Stir 12 hours
- Washed and concentrated Au NPs with TFF
- Removed majority of PVV with dilute NaBH4
- Washed and concentrated Au NPs again
- Final solution contained Au NPs in pure water
- Added Ethylene glycol and ethanol to form printable ink
- Ethylene glycol added to increase viscosity
- Ethanol added to improve drying of prints
- Final Au nanoparticle concentration ~18%

$$C_0 = pt\,(2l - a + 2w)\left(\frac{2n-1}{d}\right)\varepsilon_0$$







K.Fujimoto, npj Flex Electron, 2020

III. Results/Discussion

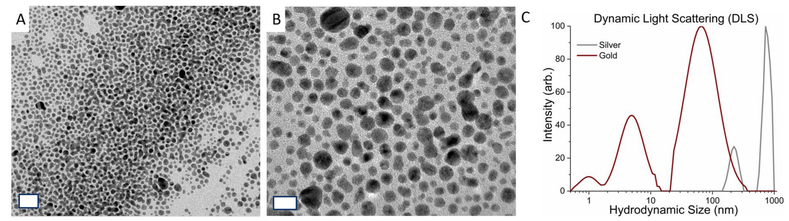


Figure #2: (A-B) TEM images of synthesized Au nanoparticles (A) scalebar 20 nm; (B) 10 nm.
(C) DLS of SIJ Ag ink and synthesized Au nanoparticles. Au nanoparticles have a much smaller hydrodynamic size than commercially purchased SIJ Ag.

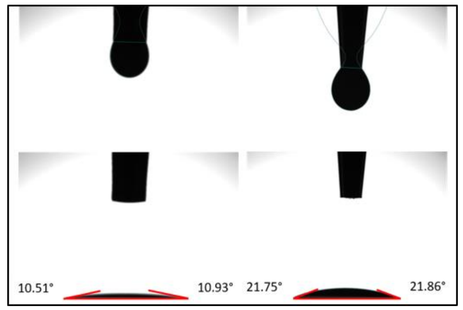


Figure #3: Optical tensiometer measurements of silver and gold ink. Top Panel: Pendant drop test for surface tension of (A) Ag ink for surface tension (B) Au ink for surface tension. Bottom panel: Contact angle measurement on glass slide (C) Ag ink (D) Au ink.

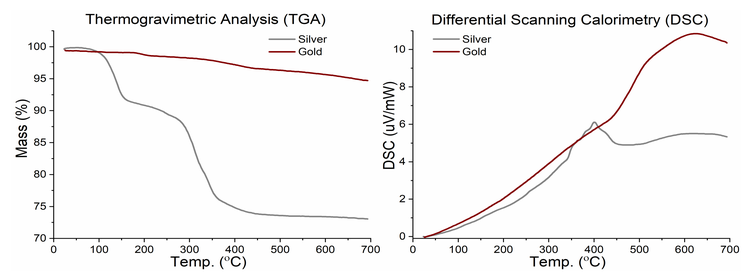


Figure #4: Thermogravimetric analysis and differential scanning calorimetry of nanoparticle inks. Au ink has little weight loss over a wide temperature range while silver shows ~30% weight loss due to polymer content-indicating minimum sintering temperature of 350° C

IV. Conclusion/ Future Work

A gold ink was synthesized that meets the technical requirements of SIJ printer, which was verified through TEM, DSC/TGA, DLS and contact angle measurements. Based on the observed characteristics it is anticipated that the as-synthesized gold ink can be printed with the SIJ printer.

Future Work:

- Verify Super Ink Jet printer compatibility
- Determine achievable resolution for the gold ink.
- Verify print quality.
- Print strain gauges and evaluate performance in extreme environments
- Use a similar process to develop additional inks (e.g. Pt) to expand the library of available inks for SIJ.

V. Acknowledgements and References

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