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3D Inkjet Printing of Electrically Active Materials

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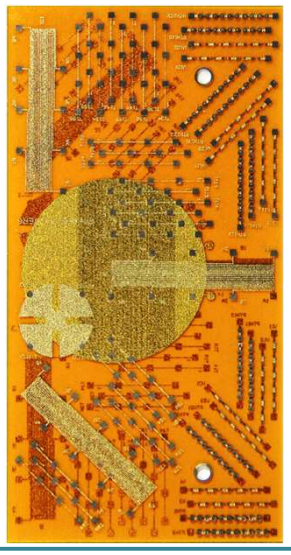
1. Introduction

Inkjet printing (IJP) can deposit micron-sized drops containing functional materials for scalable manufacture of custom electronics, such as sensors, energy storage, metamaterials, antennas, and more. Multi-material printing enables the creation of encapsulated electronics and complex devices in a single step.

This work aims to:

- Print complex, 3D, conductive structures in a dielectric matrix
- Increase conductivity
- Reduce anisotropy
- Increase geometric accuracy
- Make a tougher, stronger matrix

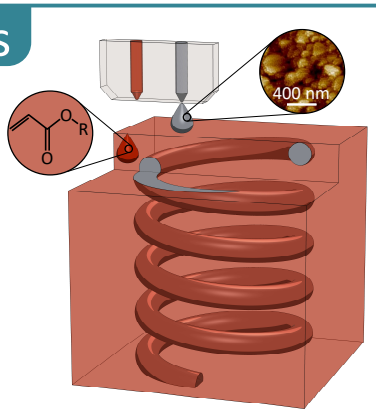


2. Functional Inks

- Ink drops are deposited onto the substrate
- Drops merge and are fixed by UV, heat etc.
- Post-processing, e.g. sintering, improves material properties

Challenges:

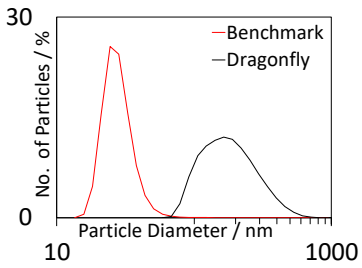
- Optimising printing and post-processing conditions for one ink that will not damage the second ink
- Maximising material loading – metal nanoparticles (NPs) are preferred to precursors, which increases printing speed[1].
- Tailoring polymer properties whilst retaining good ink rheology – often use complex monomer mixtures

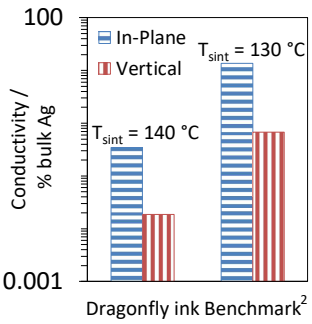


The Dragonfly LDM printer by Nano Dimension is the best-in-industry for IJP electronics. It uses a UV-curable polyacrylate to support Ag structures made from an infra-red-sintered NP ink, and is the basis for this project.

3. Conductivity Comparison

Dynamic light scattering shows that the commercial benchmark Ag NP ink from Advanced Nano Products has a narrower size distribution of smaller particles compared to the Dragonfly ink. It also has almost half the silver loading by weight.

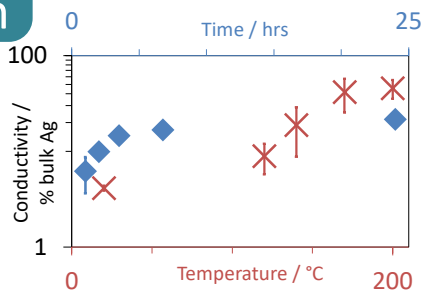


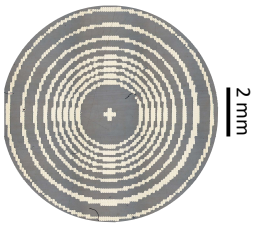


- Electrical conductivity in-plane is 8.6 $\mu\Omega^{-1}$ m^{-1} for the benchmark, and 0.3 $\mu\Omega^{-1}$ m^{-1} for the Dragonfly
- Vertical conductivity decreases for both inks due to ligand segregation between layers[2].
- Conductivity is lower in the Dragonfly ink due to contact resistance.
- The Dragonfly ink has less anisotropy, likely due to shorter ligands

4. Optimisation

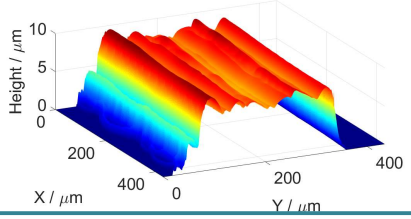
Optimisation of sintering parameters leads to in-plane conductivity of up to 75% of bulk silver's. Increasing the temperature and/or time increased conductivity, plateauing around 170 °C and 4 hours.





Log-pile printing and slight offsets between layers can also help to reduce surface roughness in multilayer prints.

Optimisation of printing parameters leads to higher accuracy of drop placement in-plane (left) and lower surface roughness (below).



5. Conclusion and Future Work

IJP can build complex, multi-material structures, including electronics. Conductivity is affected mostly by sintering parameters & needs to improve, especially vertically.

Future goals are to improve Ag ink properties (e.g. conductive ligands, Ag-salt additives) and print a device which is sensitive to 3D geometry and material properties, e.g. antennas

1. Tekin E et al. *Soft Matter* 2008;4:703
2. Trindade GF et al. *Commun Mater* 2021;2:47

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