Printed Electronics Using Magnetohydrodynamic Droplet Jetting of Molten Aluminum

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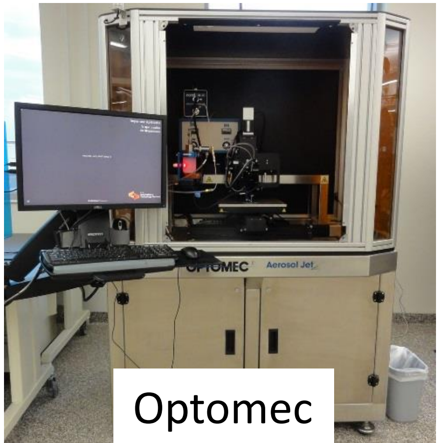
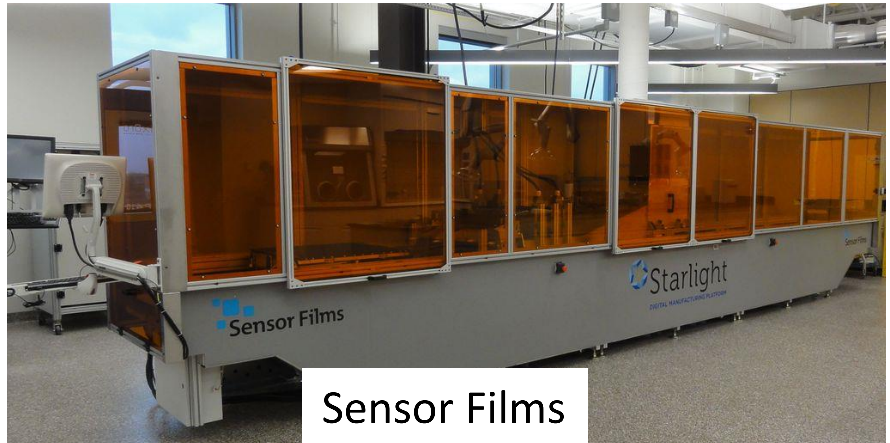
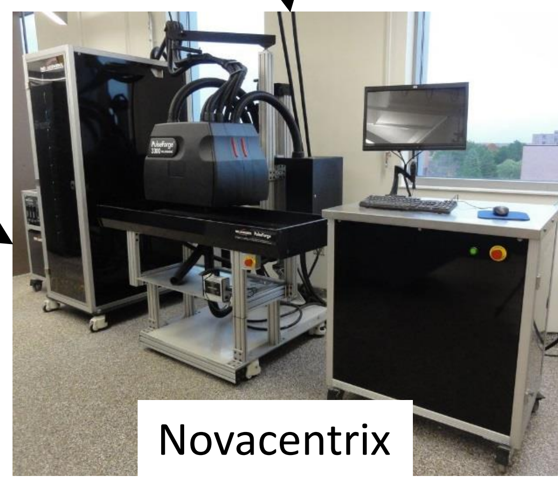
Traditional Digital Printed Electronics

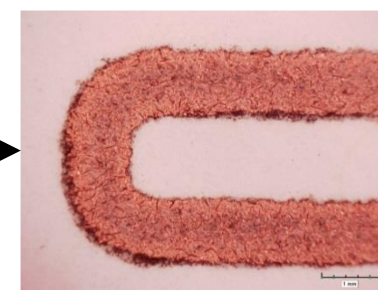

Optomec



Sensor Films


nScrypt


Novacentrix


Copper Trace

- Nanoparticle Inks
- Digital Printing
  - Aerosol Jet
  - Inkjet
  - Microdispensing
- Drying/Curing
  - Photonic Curing

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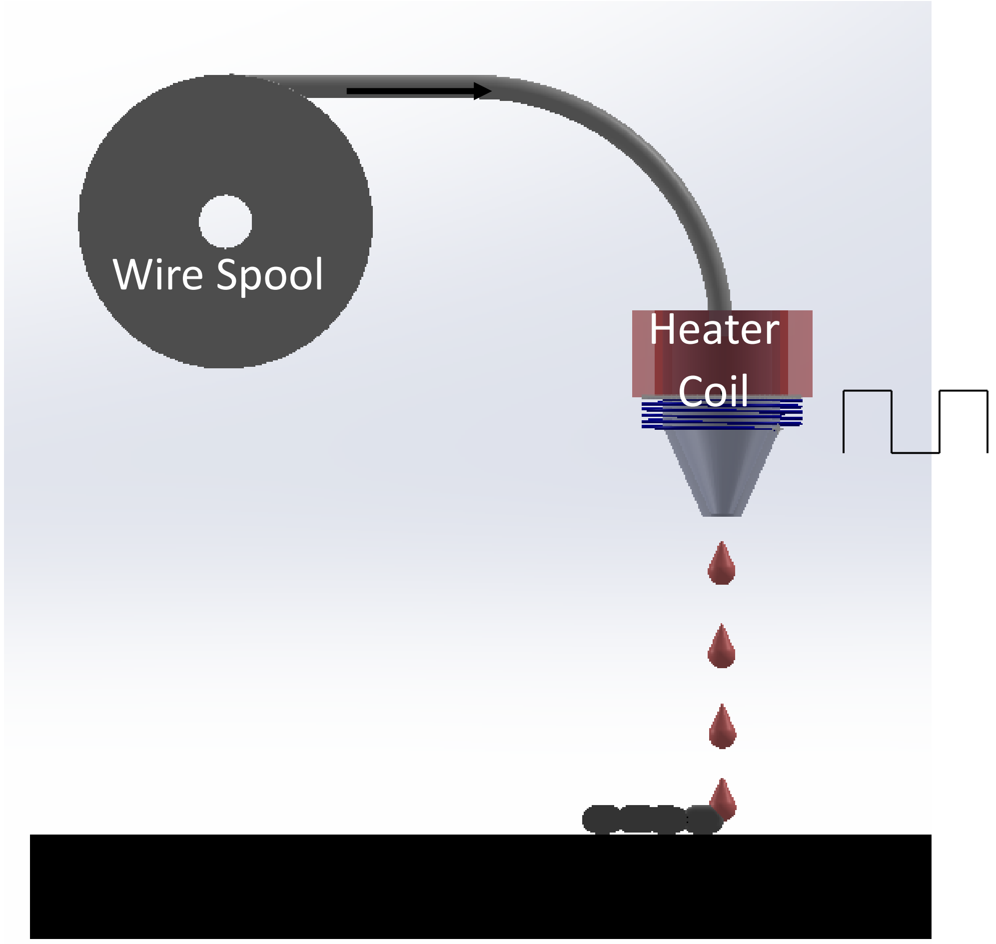
Alternative: Molten Metal Droplet Jetting (Magnetojet)

- Vader Systems
- Metal wire is fed into a micro-crucible where it is melted
- A voltage waveform is pulsed through the coil creating eddy currents in the molten metal
- Lorenz forces induce droplet jetting over a moving substrate



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Process Capabilities

- 300mm x 300mm x 300mm Build Chamber
- Current head: 1000 °C with a jetting frequency of ~500 Hz
- New head: 1400 °C with a jetting frequency of ~1000 Hz
- 50-500 µm Nozzle Diameter

4043 Aluminum jetted at 800 °C in argon

Bronze jetted at 1200 °C in argon

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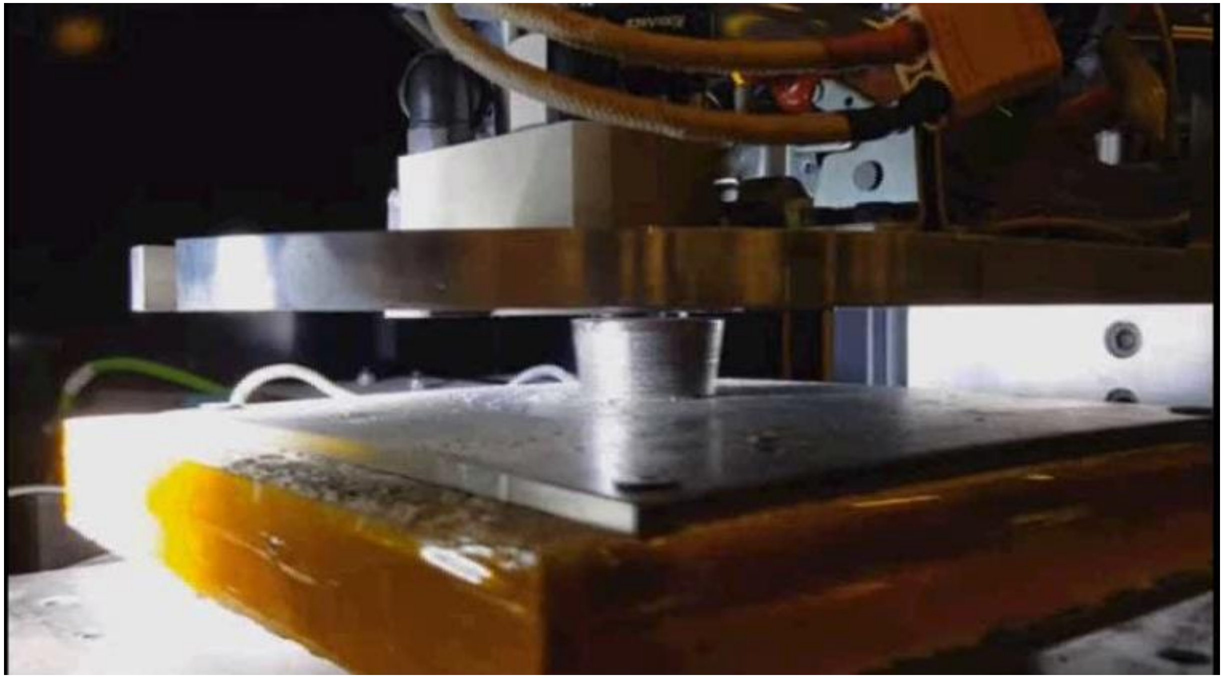
Controllable Process Parameters

- Reservoir temperature
- Platen temperature
- Nozzle diameter
- Droplet firing frequency
- Toolpath parameters (G-code)



www.vadersystems.com

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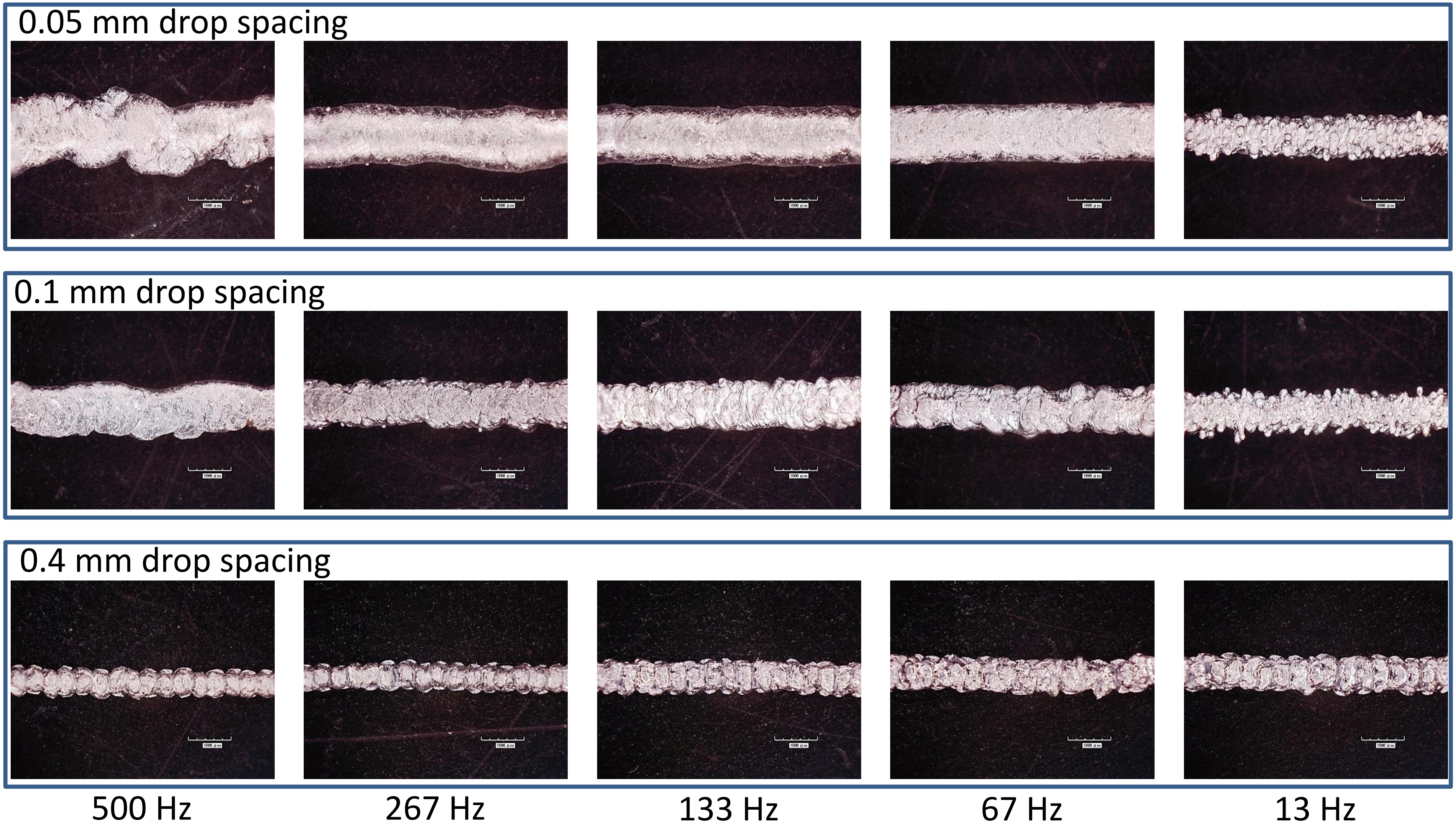
Practical Considerations

- ✓ Very Low Cost Feedstock Material
  - Aluminum Wire: <$10/lb (<$22/kg)
  - Copper Wire: <$15/lb (<$33/kg)

  } Made to order (250 lb run)
- ✓ Speed
  - Reasonably high material deposition rates
  - No post processing (drying, curing, etc.)
- ✓ Conductivity
  - 100% solid metal with no particle sintering or removal of organic material
- ✘ Feature Size
  - 250-500 µm nozzle diameters (so far)
- ✘ Range of Substrates
  - Kapton (polyimide), Ultem (polyetherimide), nylon – yes
  - PET – not yet

Single Track Printing With 500 µm Nozzle



Scale Bar = 1 mm

Droplet Diameter ≈ 0.44mm

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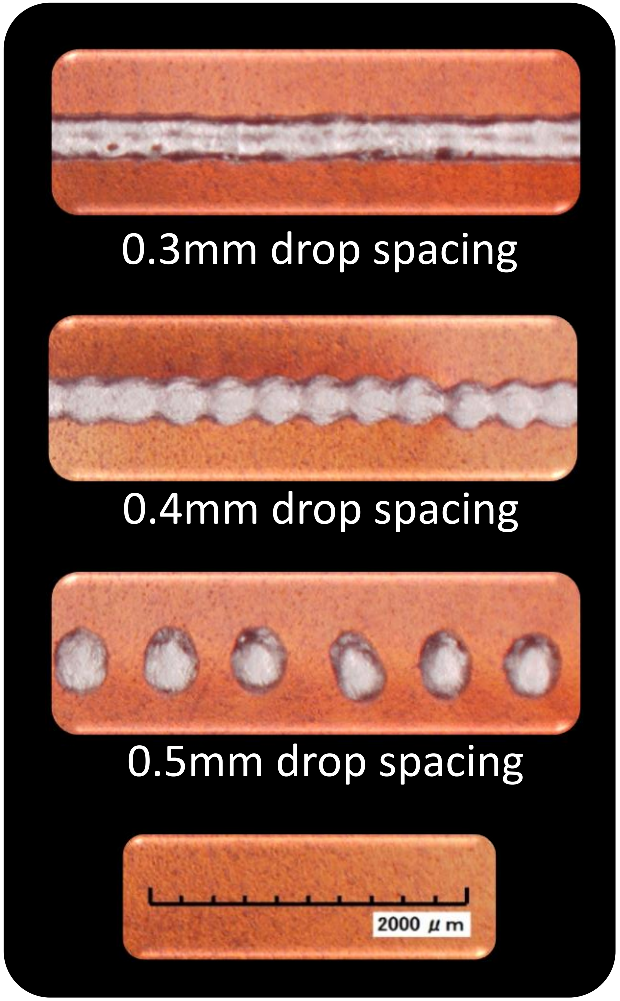
Jetting With A 250 µm Nozzle

- Pattern-Based Printing (flexo, gravure, offset, screen)
  - Line widths ~50-150 µm
- Inkjet printing processes
  - Line widths down to ~40 µm
  - A single clogged jet can result in void
- Direct-Write (Aerosol Jet, Microextrusion, etc.)
  - ~20 µm line widths
- Magnetojet Printing With 250 µm nozzle
  - 950 °C reservoir temperature
  - 150 °C substrate temperature
  - 125 Hz droplet jetting frequency



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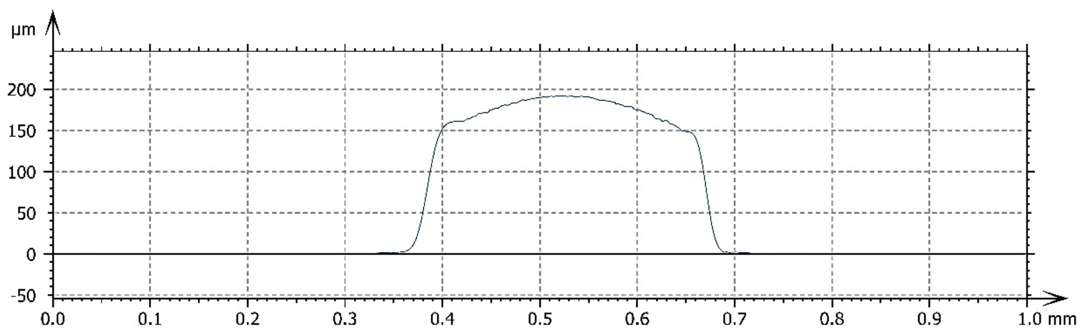
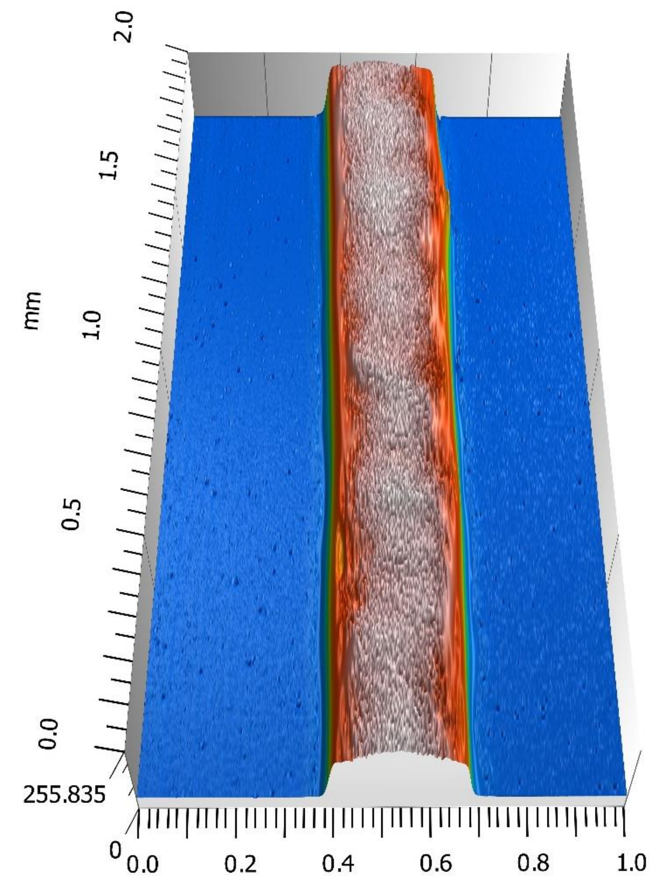
250 µm Nozzle Line Profile

- 2 mm Line Scan
  - ~280 µm wide x 175 µm tall
  - Comparable to 30 AWG solid core wire





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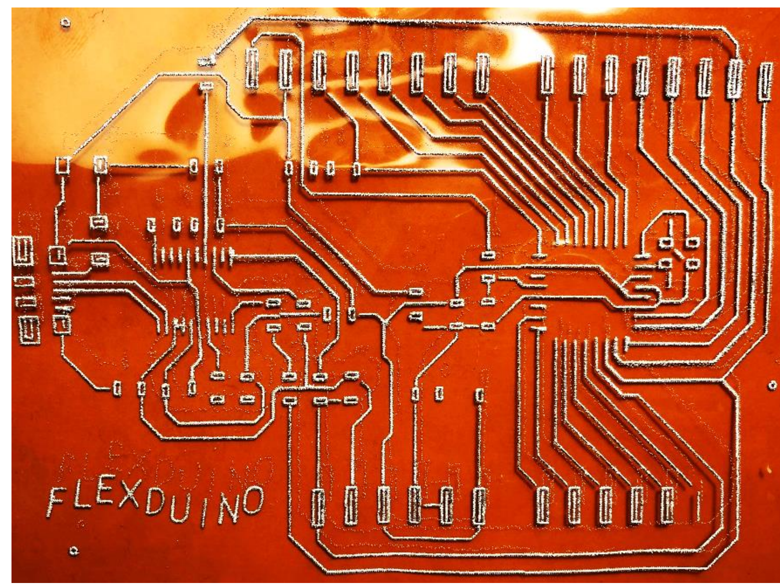
Printed Electronics Using Magneto Jetting

- Kapton substrate heated to 200-250°C results in excellent adhesion of printed traces
- Workflow development still needed to get from Gerber to G-Code toolpaths



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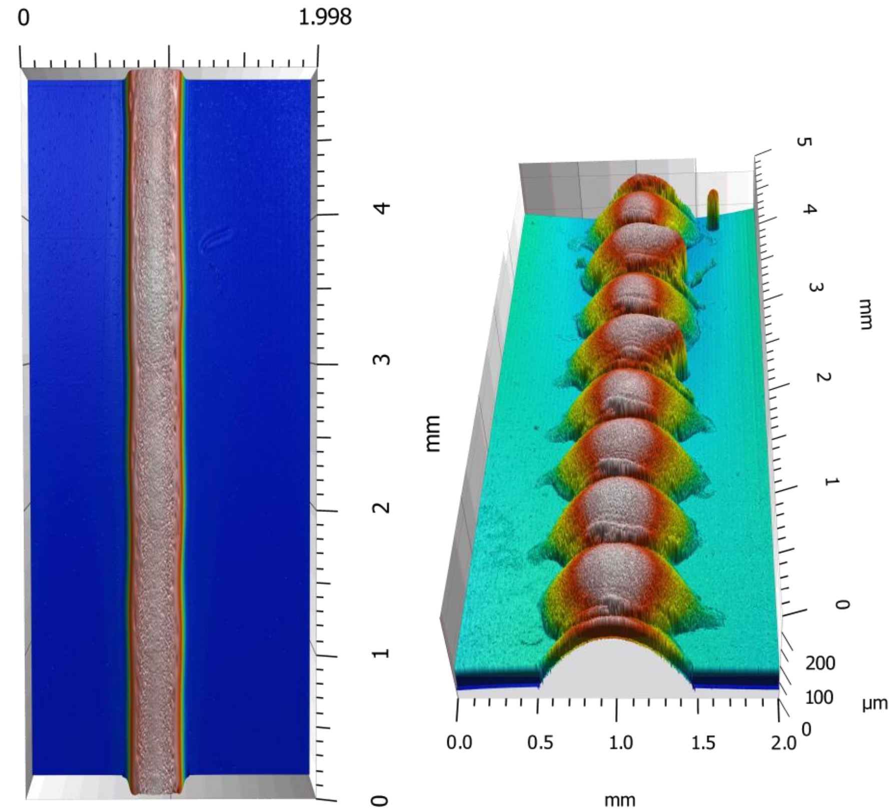
Resistivity of Printed Traces on Kapton

- Resistivity of Al 4043
  - 3.24-4.16 μΩ•cm for bulk 4043 (temper dependent)
  - 3.9 μΩ•cm for 4043 feedstock wire
  - 3.2-5.5 μΩ•cm for MJP printed traces
- Conductivity of printed aluminum traces is very close to bulk aluminum
- Excellent adhesion
- Flexible



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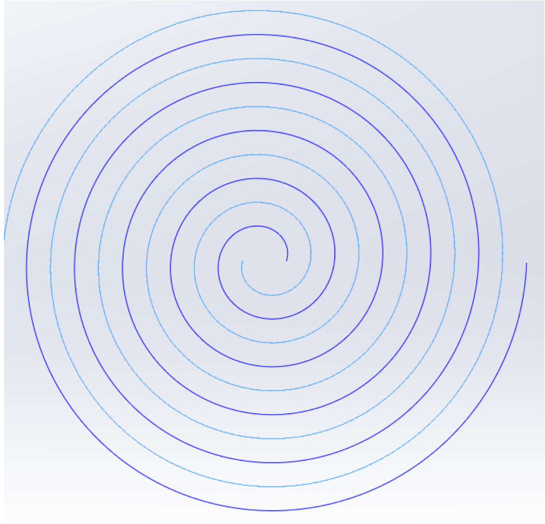
3D Antenna (preliminary work)

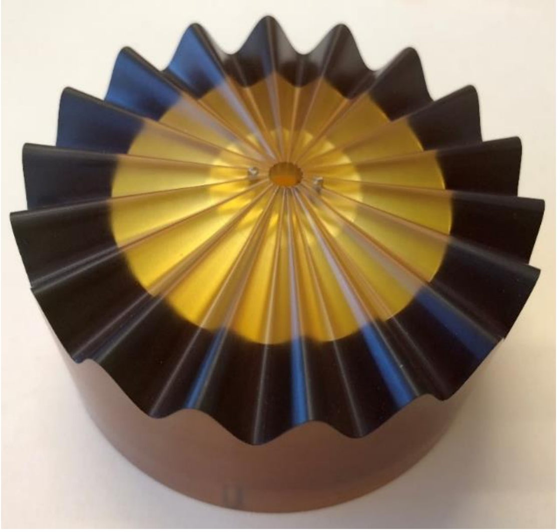
$$x(t) = (a_i + b \cdot t) \times \cos(t)$$

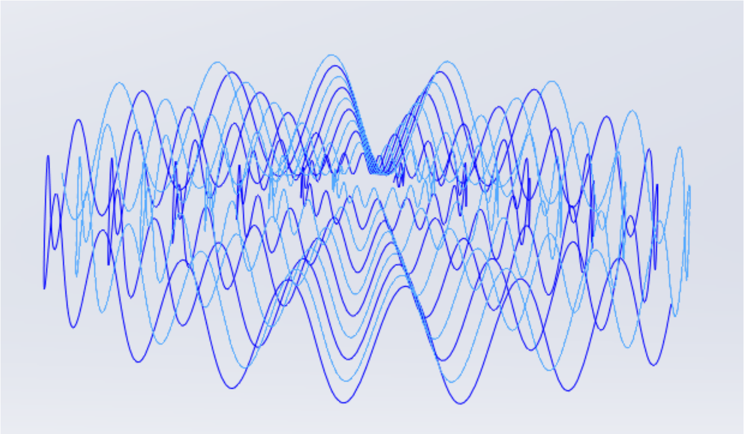
$$y(t) = (a_i + b \cdot t) \times \sin(t)$$

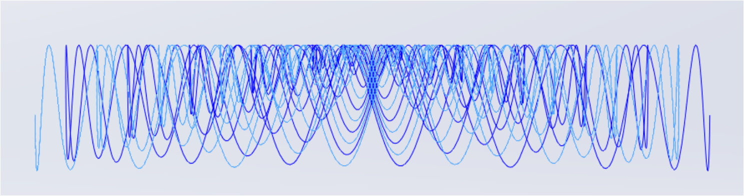
$$z(t) = \left(z_i + z_f \cdot t\right) \times \sin(w \cdot t) - z_r \cdot t + z_S$$

$$b = \frac{a_f - a_i}{2\pi \cdot n}$$









Reference: Obrien et al. (2015) IEEE Transactions on Antennas and Propagation, 63(4), pp.1843-1848.

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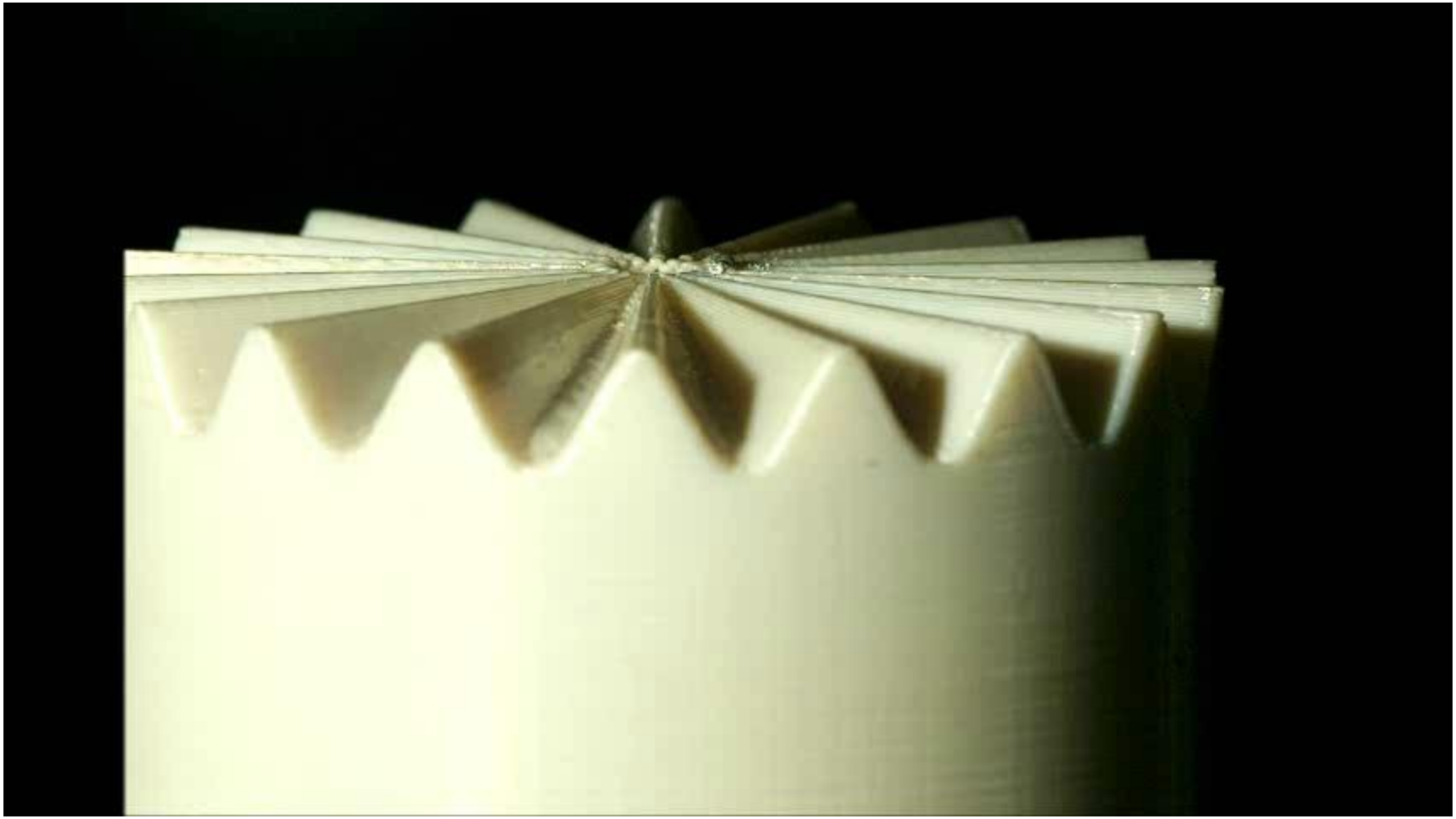
3D Antenna



Note: 500 µm nozzle used during printing in this video

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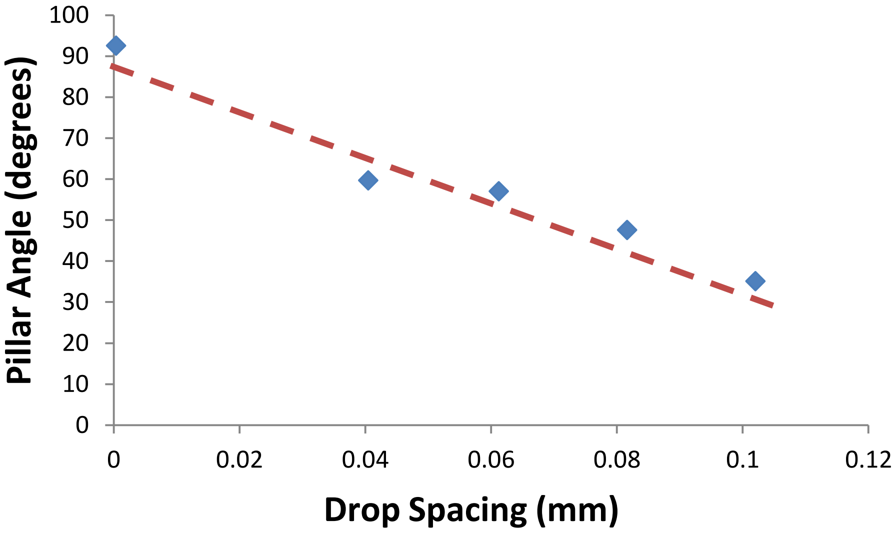
Printing Wires Without Supports



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Printed Lattice Structure

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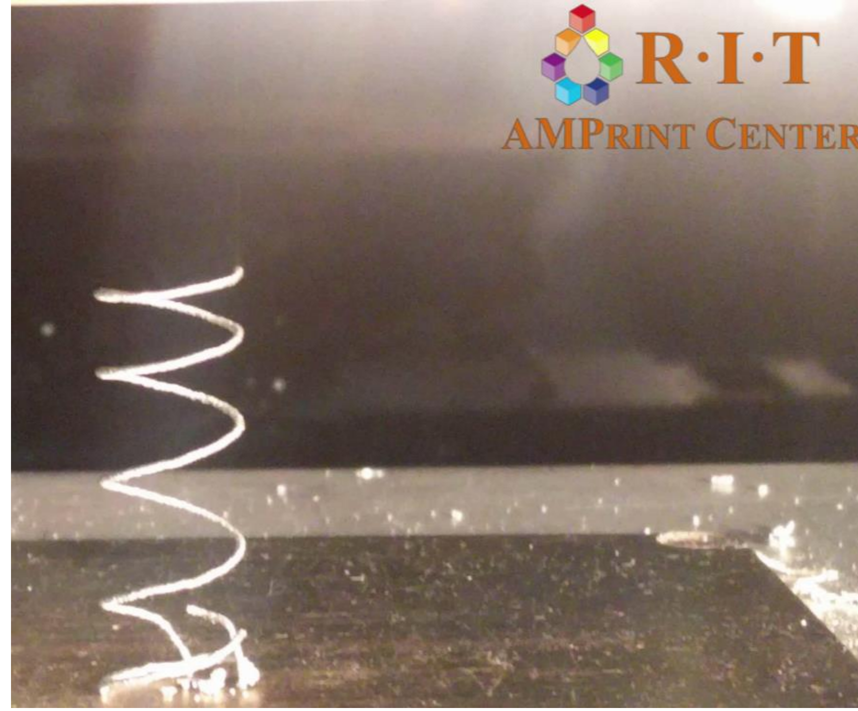
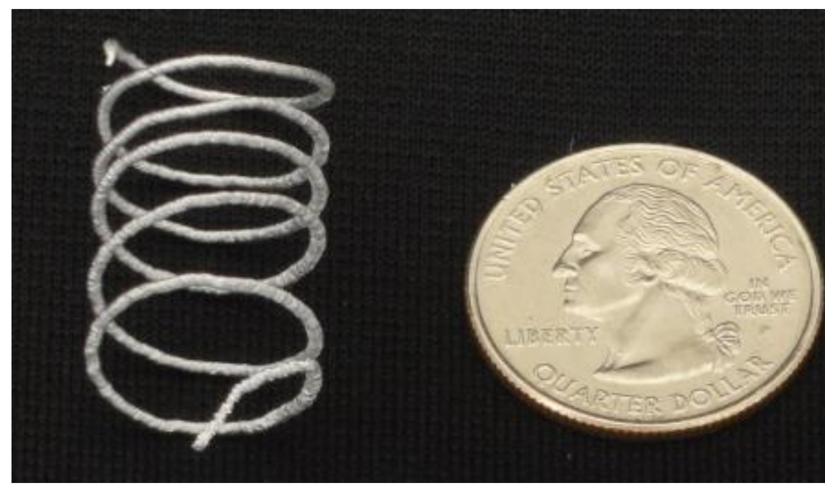
Printed Coil

- 6.25 A passing through the coil with measured resistance of 0.017 Ω
- Cool to the touch
- Potential for high current carrying applications





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Summary

- Magnetojet Printing (MJP) shows considerable promise for printed electronics applications
  - Ultra low cost feedstock material
  - Near bulk conductivity
    - Power electronics applications
  - Excellent adhesion
  - Line widths to ~250 µm demonstrated (100 µm nozzles being tested soon)
  - Non-contact printing on non-planar substrates
  - Freestanding unsupported structures

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Acknowledgments

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