Fine-Feature Additively Dry Printed Passive Wireless Sensor Tag

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Introduction

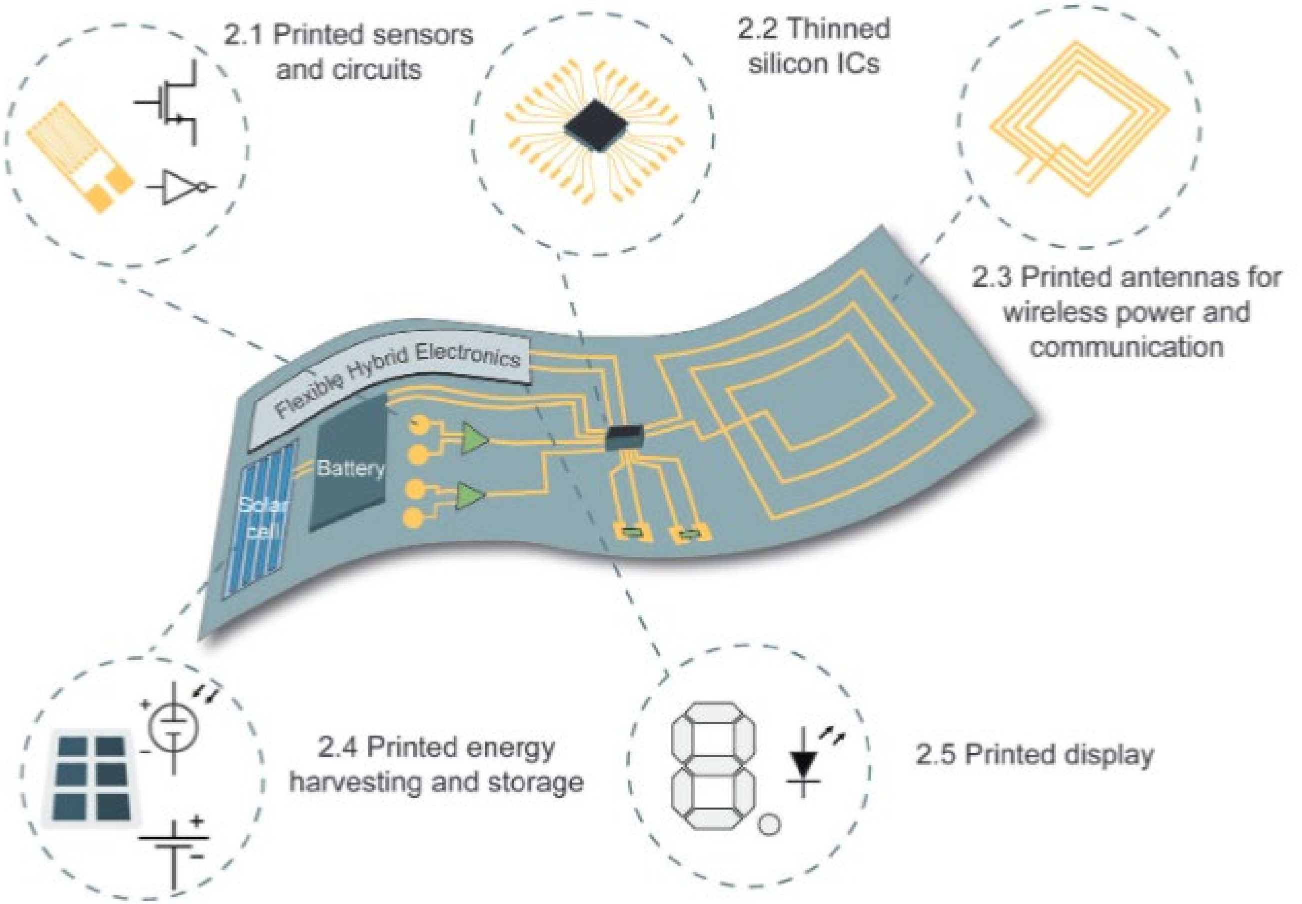
- Wireless sensor tags have many useful applications:
  - Example: RFID tags with integrated sensing functions
  - Can be realized in mature technologies such as flexible polyimide PCB
- 3D printed electronics technologies have the potential for vastly improving wireless sensor tags
  - Materials
  - Applications
  - Cost
- However, ink- and aerosol-based 3D printed electronics have limitations
- A new improved 3D printed electronics technology will be presented here
  - Laser-based additive nanomanufacturing (ANM)
  - Demonstration: an inductively coupled wireless tag

Why Direct Writing?

- Conventional printing techniques (such as offset printing and screen printing) are typically designed to print on rigid, flat surfaces and are not compatible with flexible substrates.
  - Flexible substrates cannot tolerate high temperature processes

- Roll to roll
  - Not ideal for novel ideas
  - Limited material selections

➢ *Direct Writing*
  ➢ *Suitable for wide range of substrates*
  ➢ *Cost-effective*
  ➢ *No need for mask*



https://doi.org/10.1002/adma.201905279

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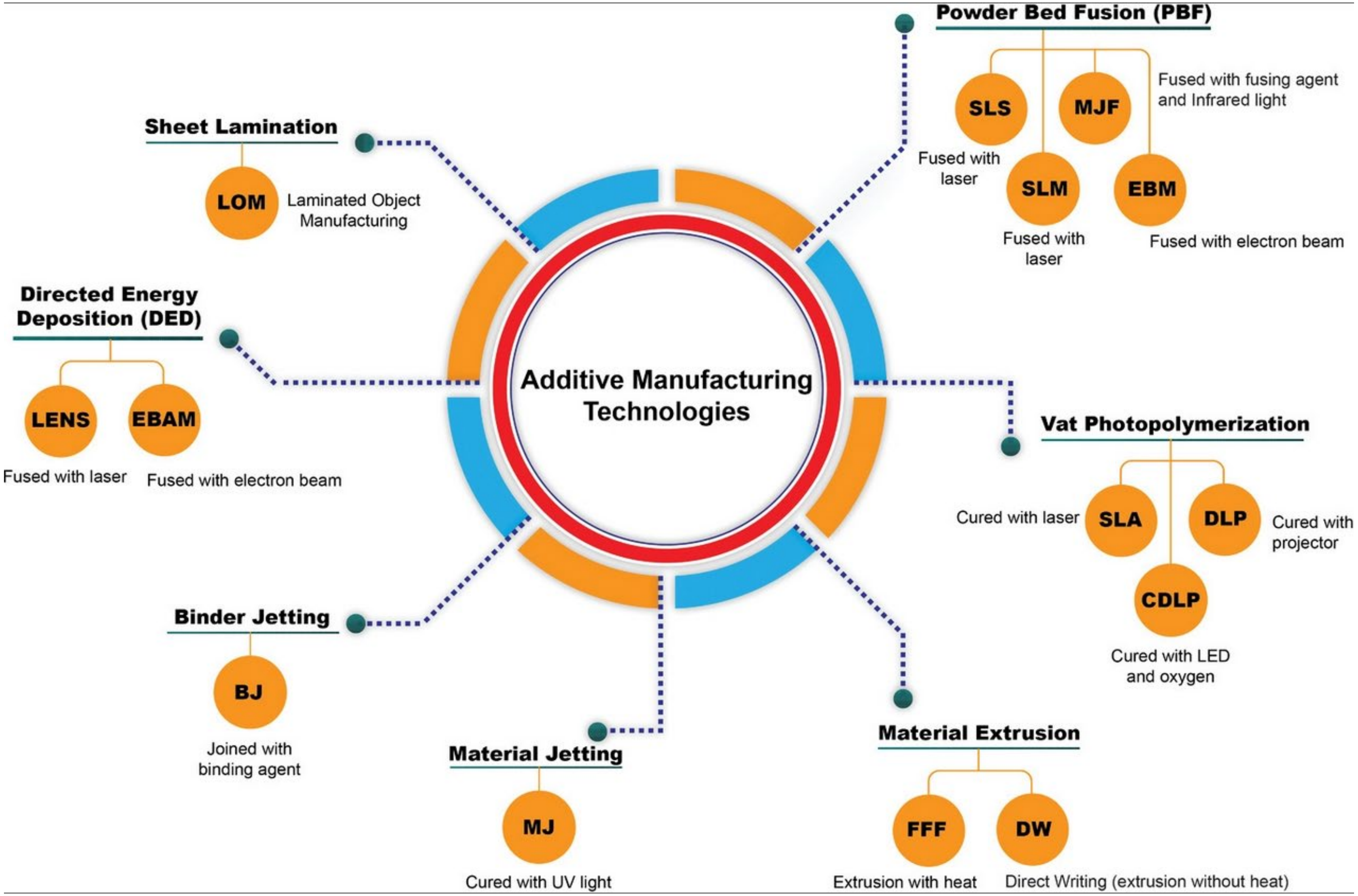
Additive Manufacturing

- Seven AM technologies are currently available
  - Most of them are ***macro scale***
- Micro scale:
  - Inkjet printing (IJP) and aerosol jet printing (AJP)



Rafiee M, Farahani RD, Therriault D. Multi-material 3D and 4D printing: a survey. Advanced Science. 2020 Jun;7(12):1902307.

Challenges

- Some challenges of IJP and AJP are

  I. These methods are ink-based. Inks contain various materials, such as metals, ceramics, and plastics, along with ***additives and solvents***

  II. The inks and solvents not only make printing non-pure and contaminated, but also may require post-processing to remove the additives and solvents

  III. Cleaning of the nozzle to avoid blockage

  IV. Print consistency & repeatability are hard to achieve

❖ A solution?

  ❖ Additive nanomanufacturing (ANM)

Lall, P., Goyal, K., and Miller, S. (April 22, 2022). "Multilayer Conductive Metallization With Offset Vias Using Aerosol Jet Technology." ASME. *J. Electron. Packag*. June 2022; 144(2): 021119.

Laser-Based Additive Nanomanufacturing (ANM)

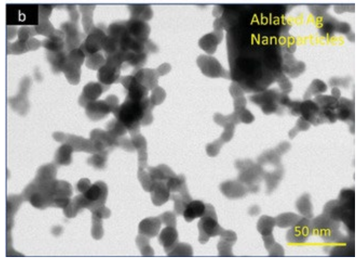
ANM PROCESS:

- Generating amorphous nanoparticles using a laser ablation process
- Delivery of generated nanoparticles via a carrier gas such as Ar
- Sintering of dry nanoparticles using a secondary laser
- Scanning of stage

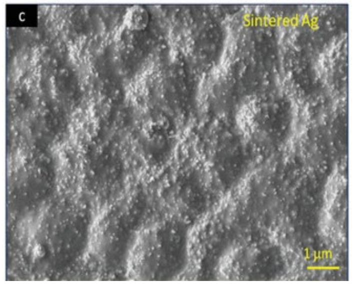
Key features of ANM system

- Generates dry and pure nanoparticles
- Compatible with rigid and flexible substrates
- Capable of patterning different shapes
- Non-contact process

Generated nanoparticles

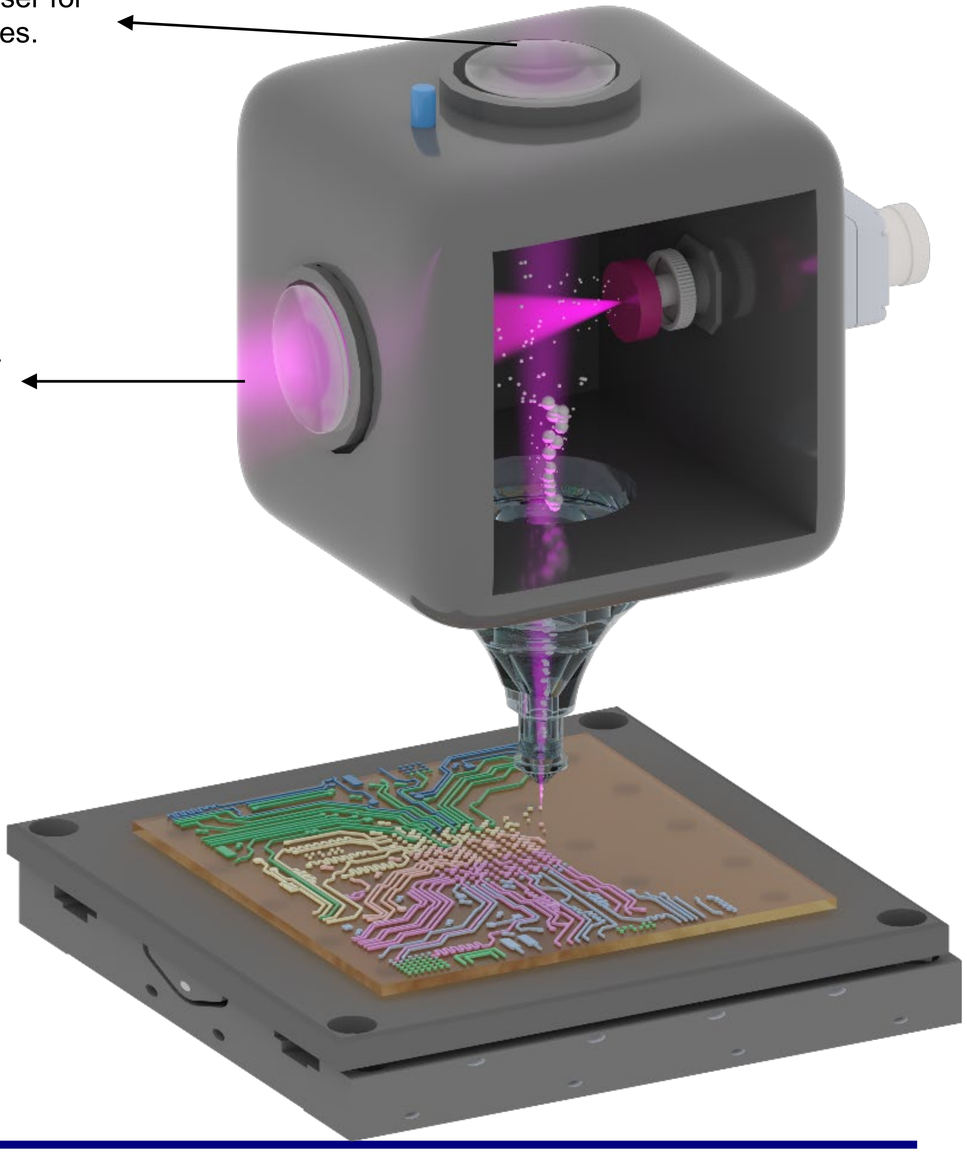


Sintered nanoparticles



1064nm pulsed fiber laser for sintering of nanoparticles.

1064nm pulsed nanosecond fiber laser for ablation of a solid target



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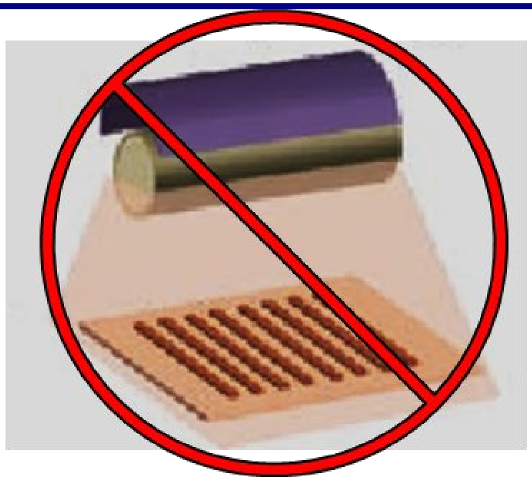
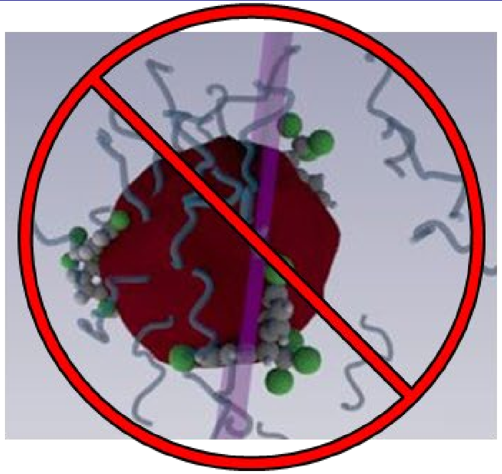
Dry Printing Advantages

No need for Ink

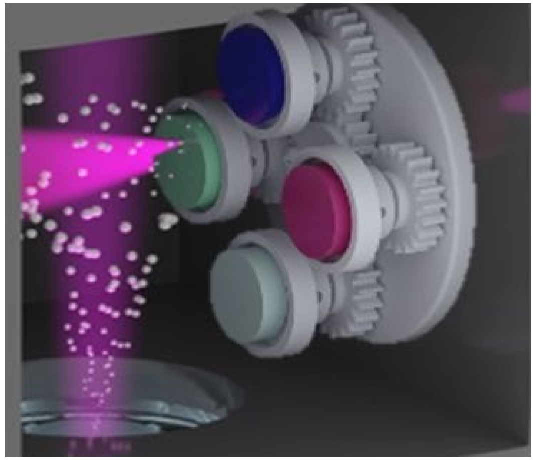


No post-processing



No contamination

Eco-Friendly



Multimaterials

Cost-Effective

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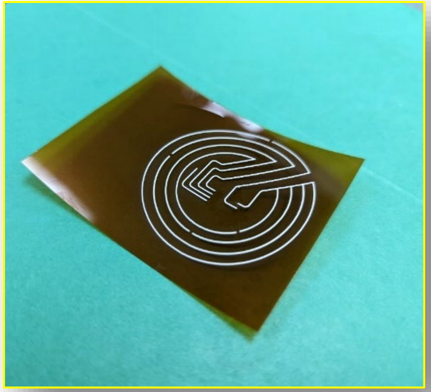
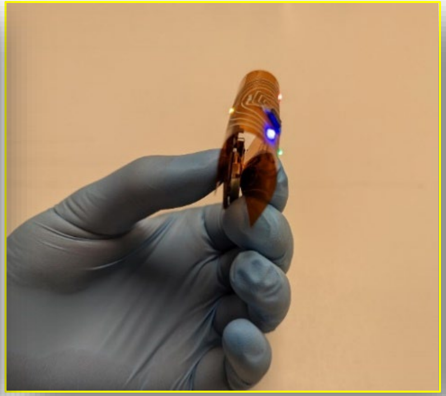
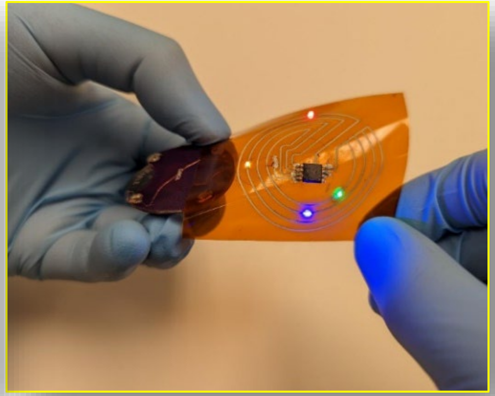
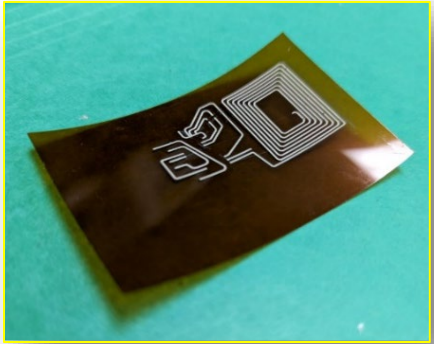
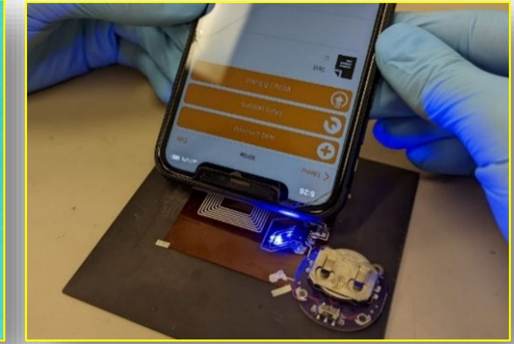
Single Material Printed by ANM

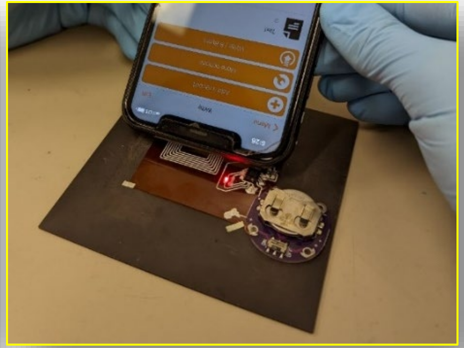


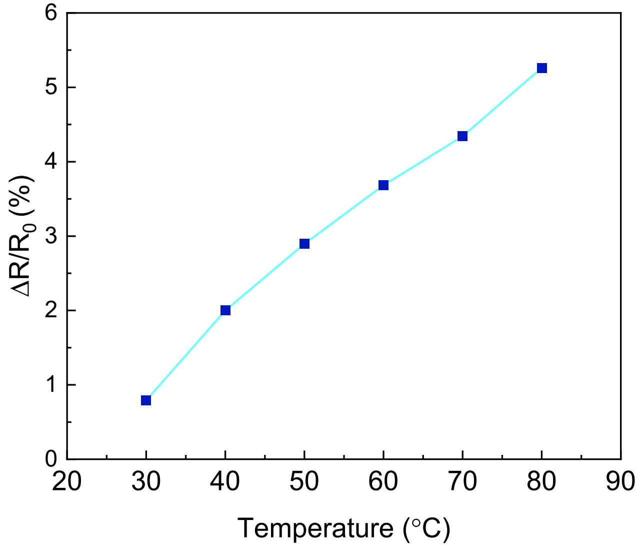












Ahmadi, Z., et. Al, *Adv. Mater. Interfaces* 2022, 2102569. https://doi.org/10.1002/admi.202102569

ANM System Parameters

- Parameters governing the printing:
  - Ablation laser
    - 1064nm fiber pulsed nanosecond laser (60W max power)
  - Sintering laser
    - 1064nm fiber pulsed nanosecond laser (20W max power)
  - Nozzle size
    - 100 um to 1 mm
  - Gas flow rate
    - 0.5 to 2 SLPM
  - Printing speed
    - 1 to 50 mm/s

- Materials Printed:
  - Metals such as Silver (Ag)
  - Metal Oxides such as barium titanate (BTO), titanium dioxide (TiO_2), tin oxide (SnO), aluminum oxide (Al_2O_3)
  - Semiconductors such as zinc oxide (ZnO)
- All nanoparticles are dry, solvent/additive free
- No post processing is needed

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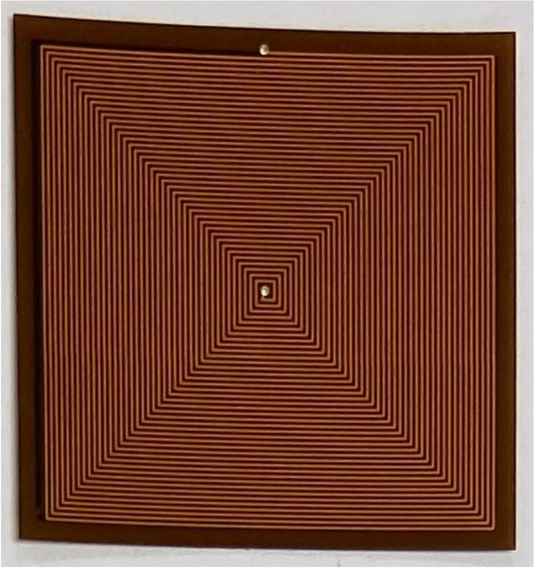
Application to Passive Wireless Sensor Tags

- Similar to an RFID tag
- Uses a printed LC tank circuit
  - Planar inductor: L
  - IDE capacitor or inductor's self capacitance: C
- Planar inductor inductively couples the tank circuit to a base station oscillator
  - Affects the oscillator's output frequency
- Either L or C can be the sensor

Example LC sensor tag in traditional flexible PCB technology

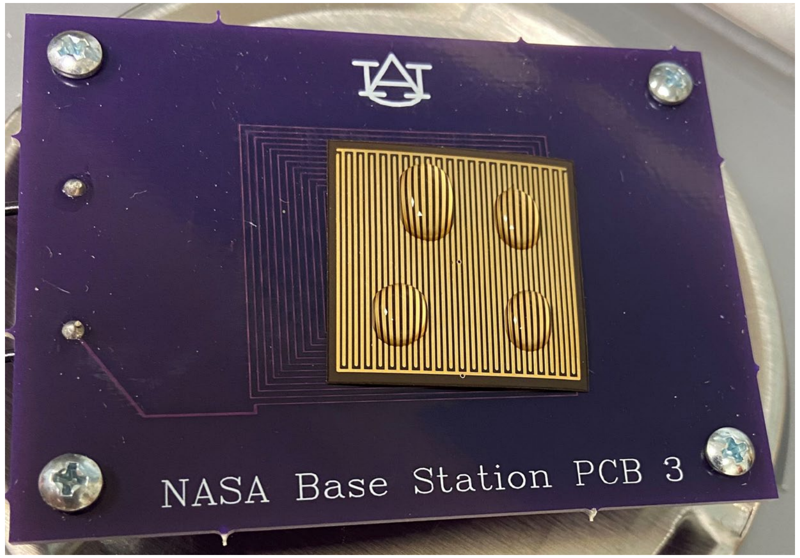
IDE sense capacitor on one side

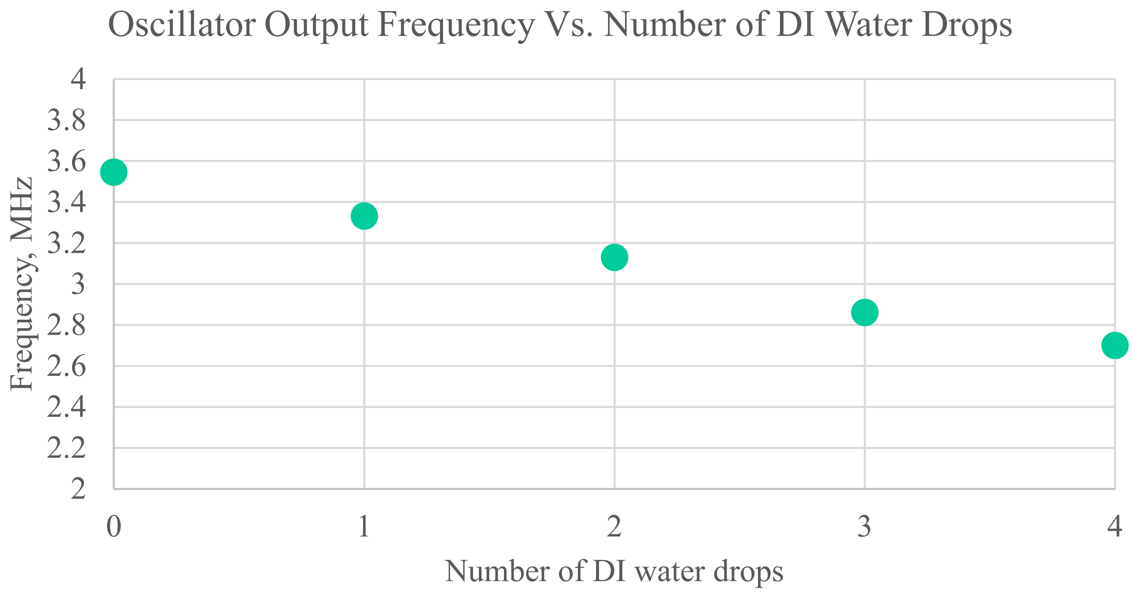


Planar inductor on other side

Wireless Sensor Tag Demonstration

- Polyimide PCB sensor tag demonstrated with the inductively coupled base station oscillator
- DI water drops added to IDE sensing capacitor
  - Insulating solder mask coating
  - Each drop approximately 50 mg
- Each drop increases the tag capacitance
  - Decreases the oscillator's frequency: $freq \propto \frac{1}{\sqrt{LC}}$

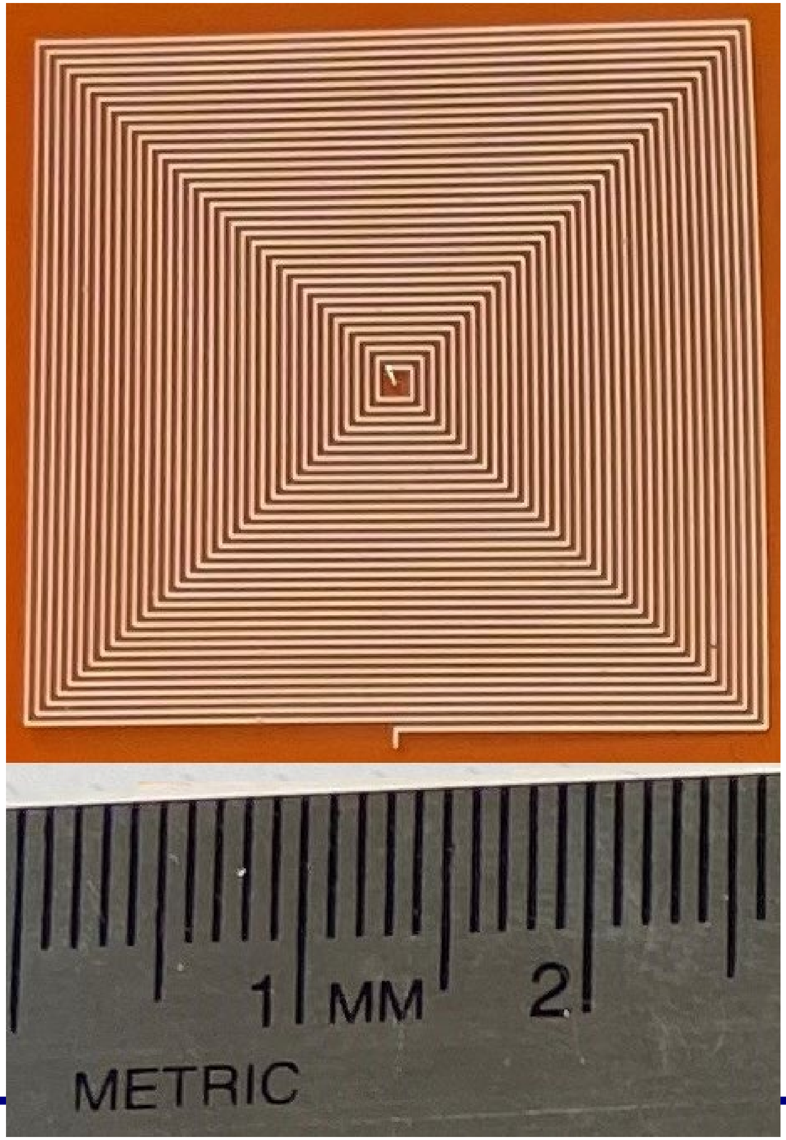




ANM Printed Passive Wireless Sensor Tag

- Substrate: polyimide
- Planar printed inductor
  - 34.5 turns
  - ~2.6 cm across
  - ~151 µm trace width
  - ~223 µm gap width
  - ~4 µm thick Ag
  - Estimated inductance: ~13 µH
- The self capacitance between turns forms an LC tank circuit with the inductor

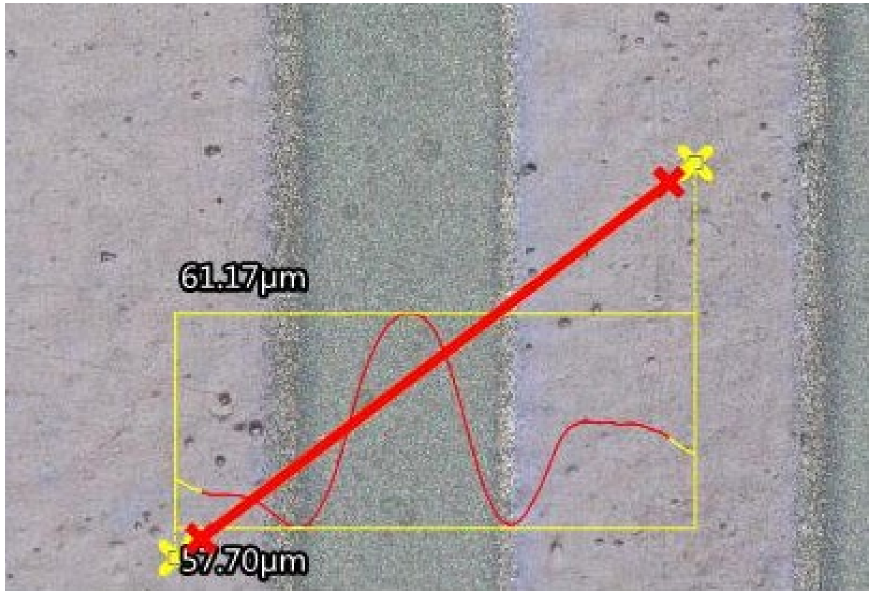
ANM Printed Planar Inductor

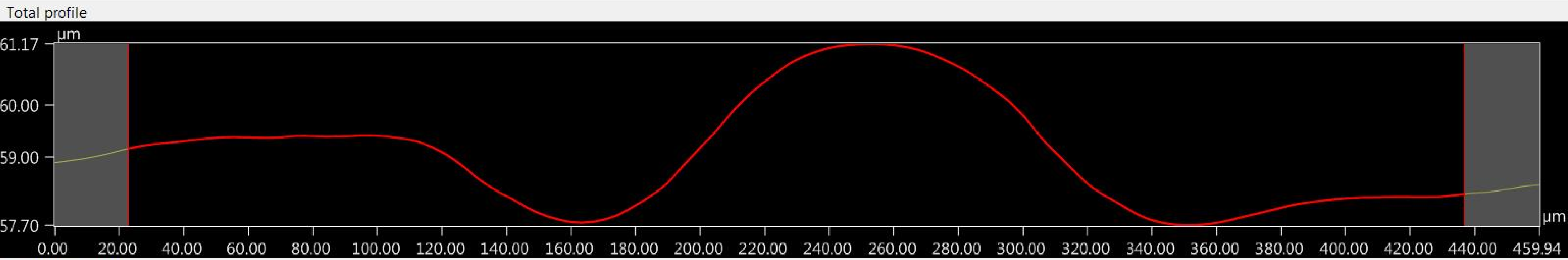


Analysis of the Inductor’s Printed Trace

- Trace height analyzed using optical microscopy
- Trace thickness approximately 4 µm
- Side trenches are an artifact of the laser sintering

Space Trace Space





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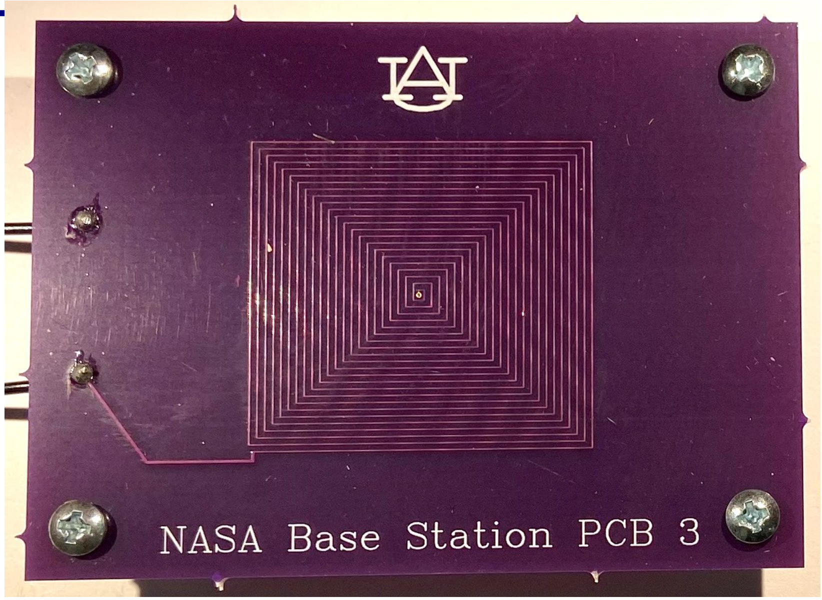
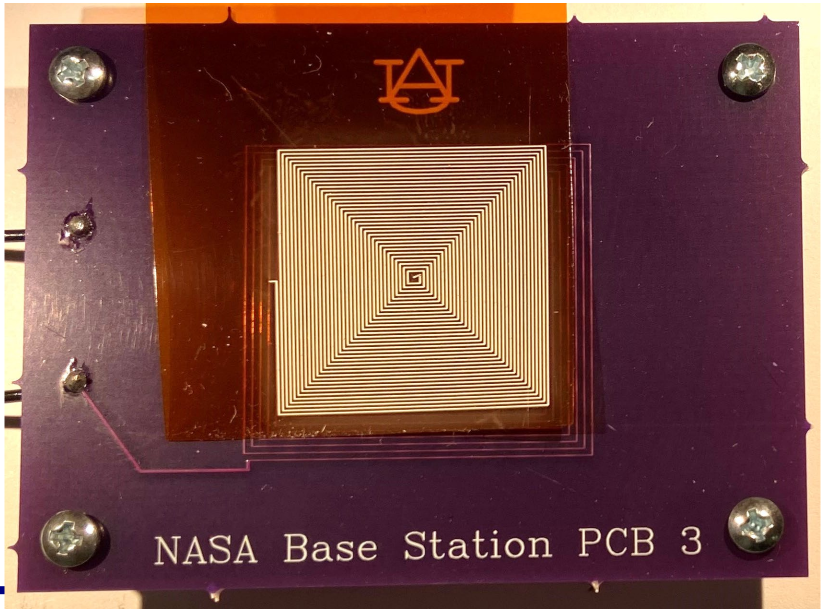
Wireless Testing Plan for the Planar Inductor

- Printed inductor placed in close proximity to the base station inductor
  - Tag inductor inductively couples to base station inductor
  - Coupled LC tank circuit from the tag tunes the base station connected feedback oscillator circuit
  - Output frequency is a function of the tag’s L and C
  - L increases : oscillator frequency decreases
  - C increases : oscillator frequency decreases
- Base station planar inductor board with and without tag:





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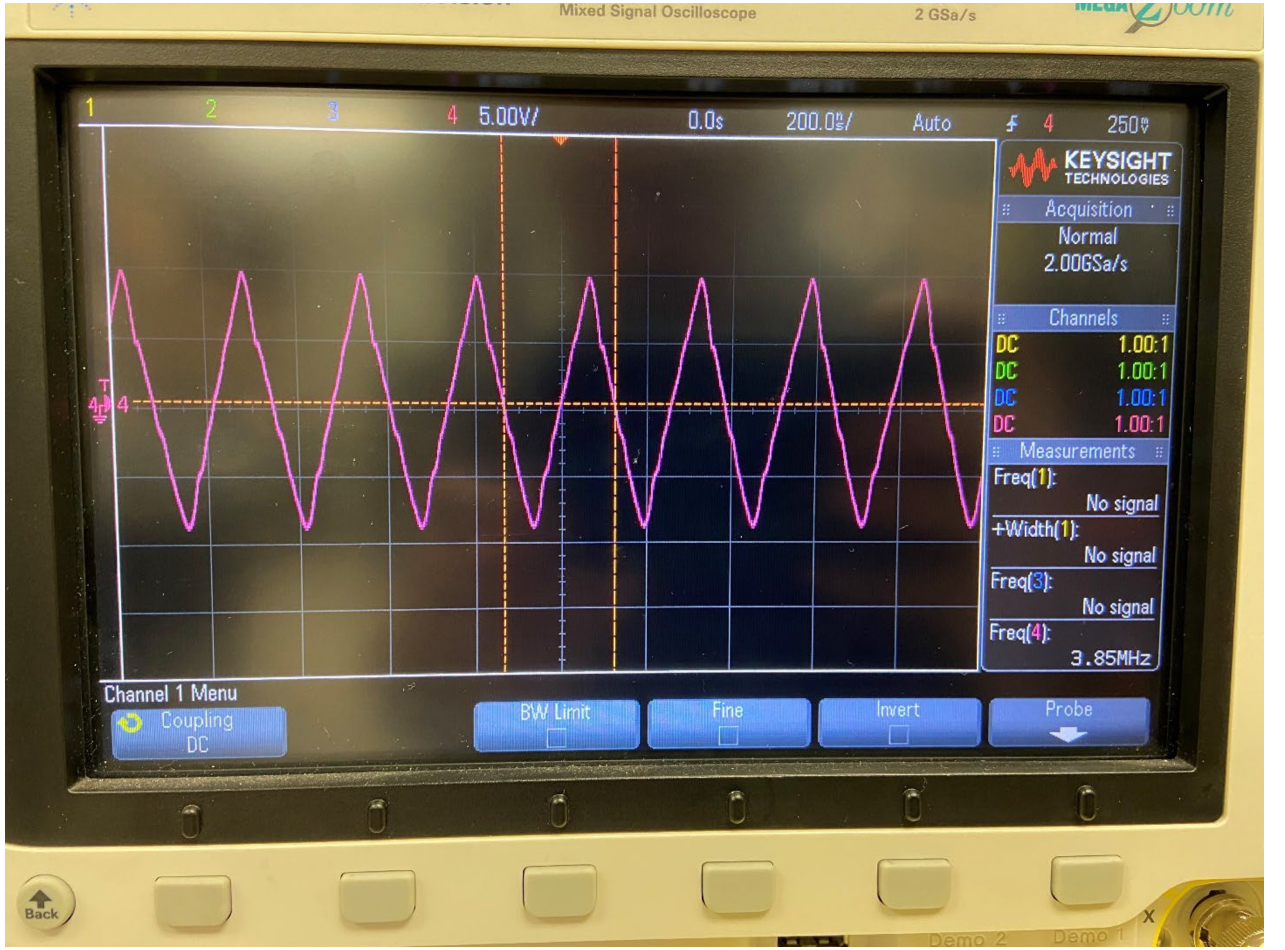
Wireless Testing Results

- The presence of the sensor tag resulted in approximately 4.2 kHz change in the oscillator's output frequency
- Test data demonstrated that the ANM printed planar inductor will inductively couple to the base station planar inductor
- Example output waveform from the detection oscillator:
- Waveform distortion likely due to gain roll-off near power supply rails
  - Served as the oscillator's AGC



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Future Work

- Using the ANM printed inductor as a wireless sensor:
  - Deforming the inductor structure will change the inductance
    - Application: structural health monitoring
  - The presence of a ferromagnetic material will increase the inductance
    - Application: corrosion product detection
  - The presence of moisture will increase the parasitic self capacitance
    - Application: moisture content measurement
    - Application: relative humidity measurement
  - An IDE sense capacitor could be integrated with the planar inductor
    - Application: higher sensitivity moisture sensing
    - But, this requires 2 printed conductive layers, 1 printed dielectric layer, and an electrically conducting via
    - An additional dielectric layer needed if the sensing IDE will be directed exposed to moisture

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Conclusion

- Wireless sensor tags have many useful applications
  - Including sensing functions integrated into RFID tags
- 3D printed electronics has the opportunity to improve the use of wireless sensor tags
  - Materials
  - Applications
  - Cost
- Traditional 3D printed electronics technologies (ink-based, aerosol-based) have limitations
- ANM significantly improves 3D printing technology
- ANM was used to produce a printed planar inductor for inductively coupling to a base station oscillator
  - Future use as a wireless sensor tag

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For Additional Information

- Regarding the ANM printing process and system: Dr. Masoud Mahjouri-Samani
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- Regarding the wireless sensor tag system: Dr. Robert Dean
  - deanron@auburn.edu

- Thank you