Reliability Investigations in Printed Electronic Assemblies

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Lockheed Martin, NCMS-AMMP, UMD MSE (Kofinas Group), UMD-SMIEL (Das group) NextFlex, Binghamton Univ.

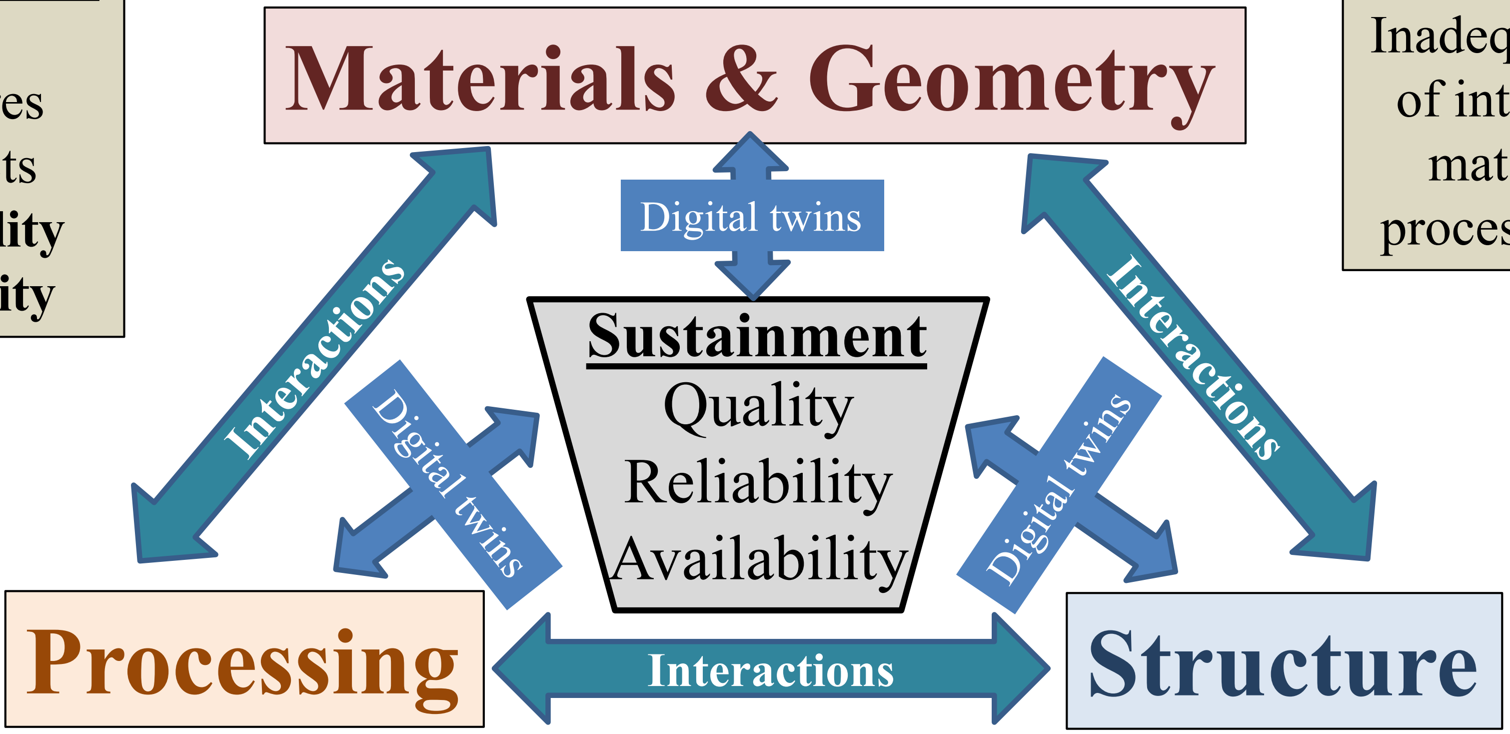
Additively Manufactured Printed Hybrid Electronics (PHE)

Dielectrics (polymers)
Conductors (metal nanoparticles)
Ink solvents and binders

Challenges in PHE:

- New material sets
- New microstructures
- New process defects
- **Excessive variability**
- **Unknown reliability**

Process Variability: Inadequate understanding of interactions between materials, geometry, processes, and structures



Aerosol jet printing
Syringe printing
Curing
Sintering
Surface preparation
Aging
Cleaning

New Reliability Challenges: Inadequate understanding of multi-physics degradation under life-cycle stresses

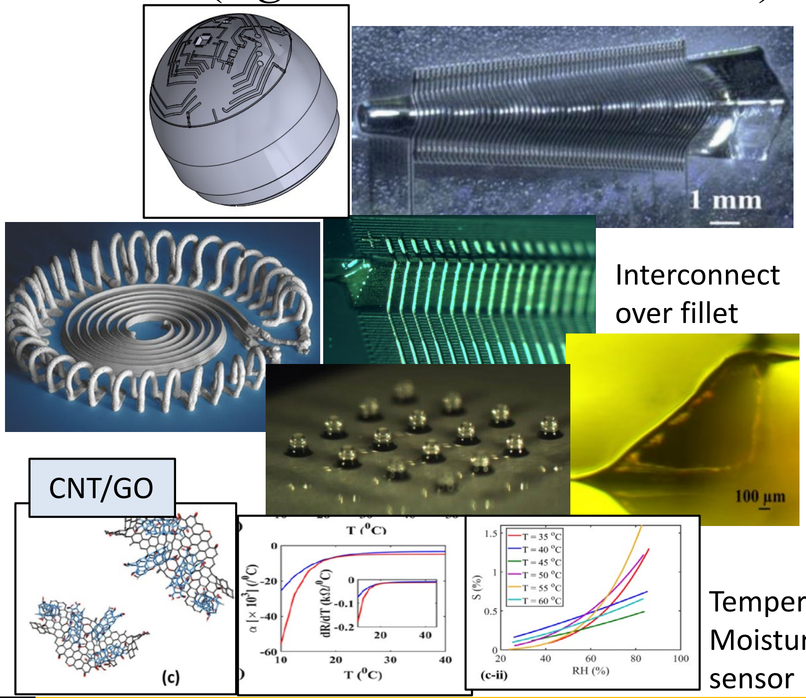
Feature-size
Overspray
Agglomeration
Porosity
Micro-cracks
Interfacial defects
Residual stresses

Additively Manufactured Printed Hybrid Electronics (PHE)

Design – Manufacturing - Performance

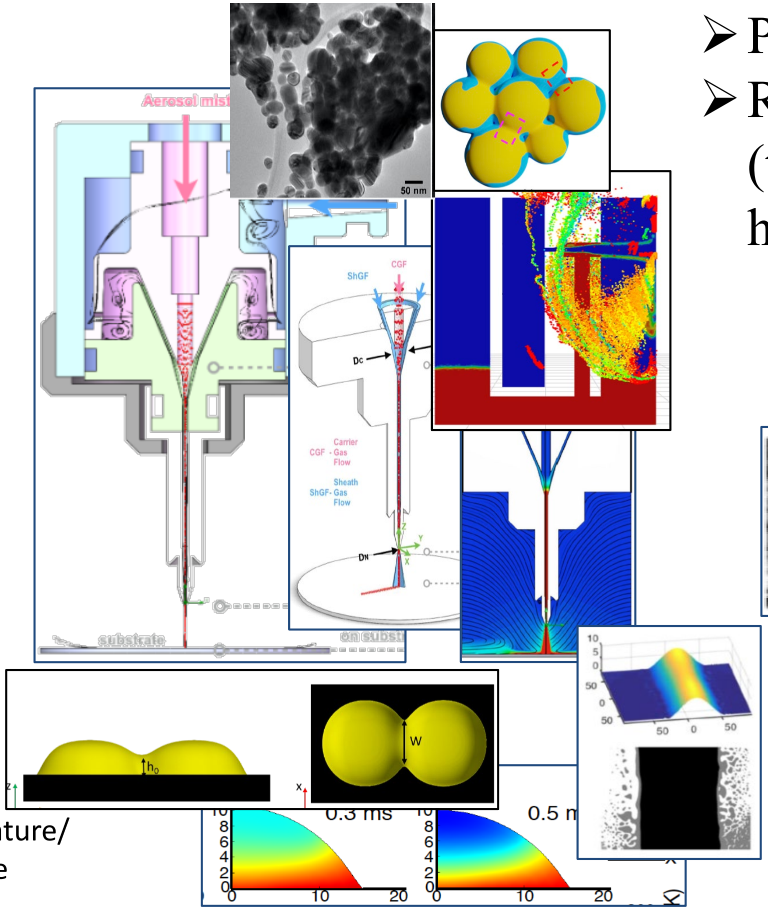
Materials & Geometry

- Polymers capable of withstanding ~160-180^{0}C
- Metallic nanoparticle-laden inks
- Specialized nanoparticle laden inks (*e.g.* CNT/GO for sensors).



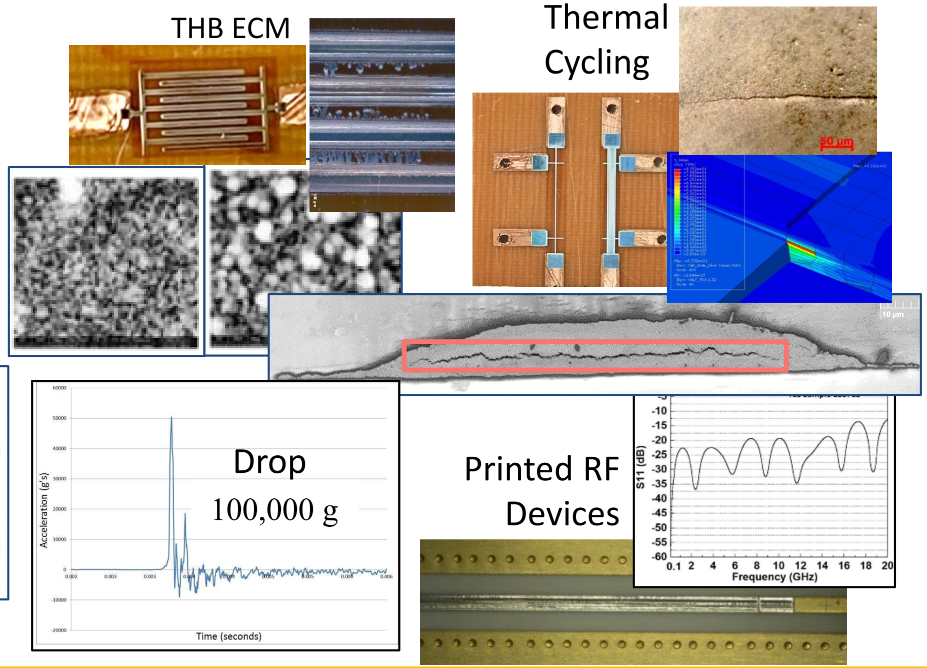
Processing

- Syringe Printing
- Aerosol Jet Printing

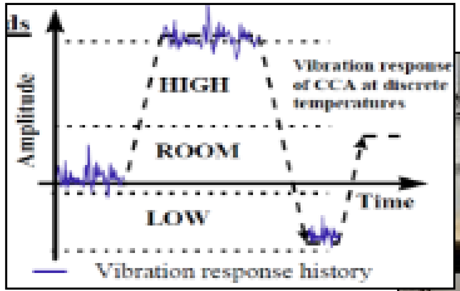


Structure/Performance/Reliability

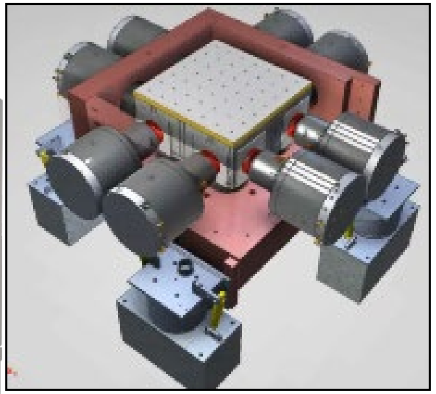
- Desired properties of printed traces
- Printability/repairability on complex surfaces
- Process variability, defects and quality
- Reliability of PHEs under life cycle stresses (temperature, humidity, flexure, vibration, high-G drop/shock)



How will PHEs be Qualified for Complex Life-Cycle Stresses ?



Combined Temperature-Vibration



Multiaxial Vibration

Temperature-Humidity-Bias

High-G Drop Testing up to 100,000g

Battery Testing

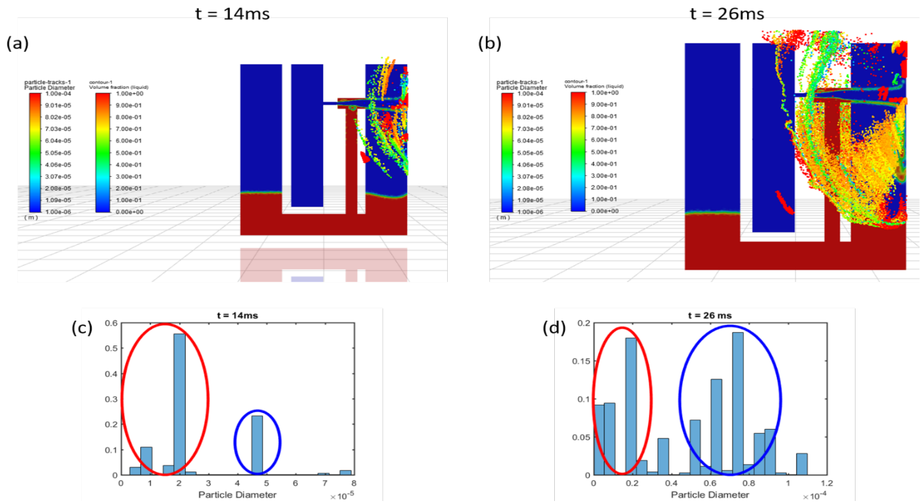
Mixed Flowing Gas Corrosion

Temperature Cycling/Shock

High Temperature Storage

Computational Fluid Dynamics Modeling for Improving Aerosol Jet Printing Processes

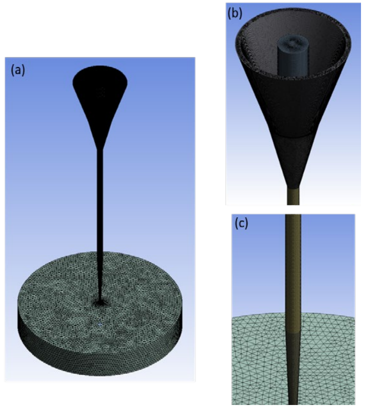
Turbulent Aerosolization process



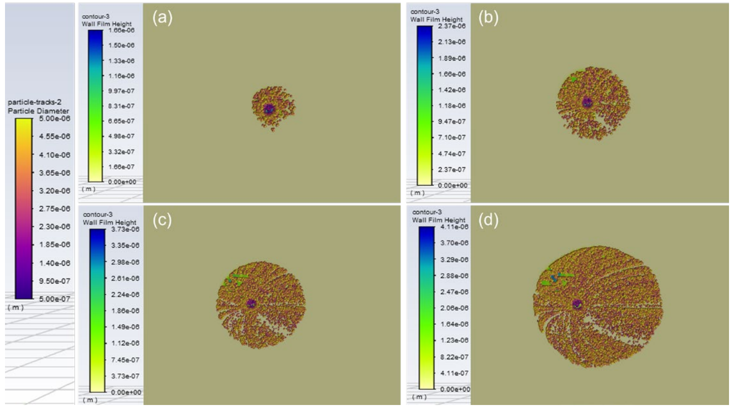
Results from CFD-based model for capturing the aerosolization process; we study the aerosolization of the NEA 121 drops

Work supported by NCMS

Transport and deposition of aerosolized drops



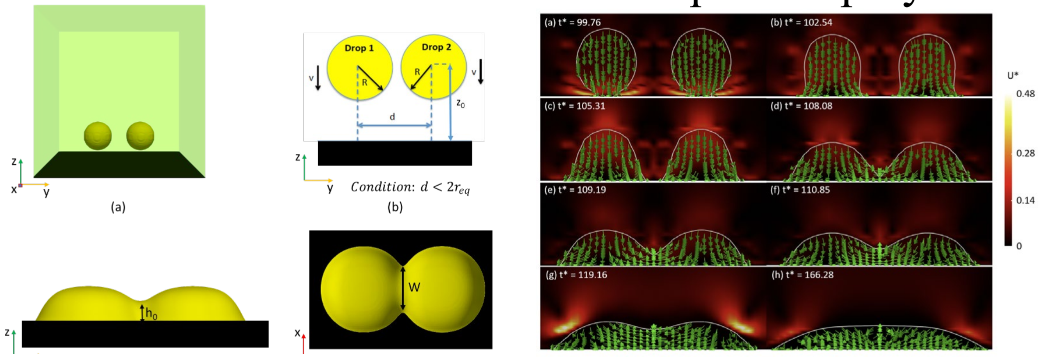
Geometry for capturing the transport of the aerosolized drops



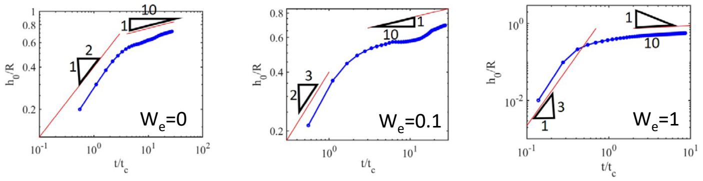
Height of the deposited Acrylic Resin Ink

Work supported by NCMS

Coalescence of Aerosol Jet deposited polymeric drops



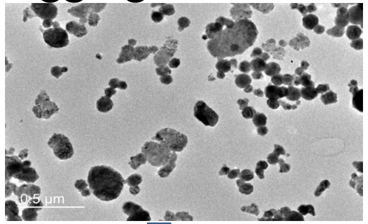
Results from CFD-based model for capturing the the coalescence of two impacting polymeric drops deposited during AJ printing



Scaling laws dictating the drop coalescence for different Weber number and different stages of coalescence

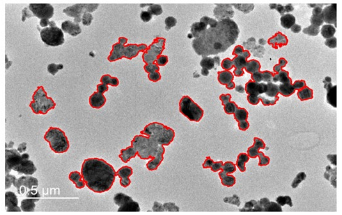
Work supported by ARL and LPS

Aggregation of the Nanoparticles during Sintering of Nanoinks

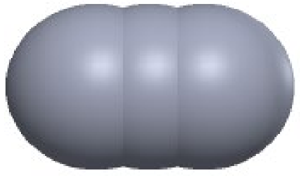


Particle tracking algorithm

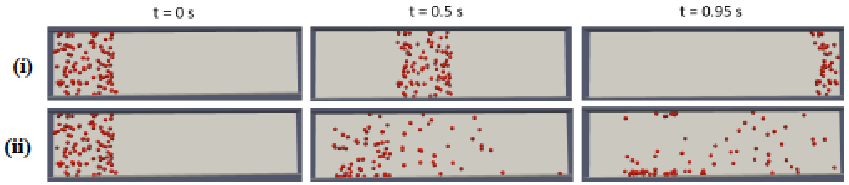
LP-TEM Measuremen



Particle size (diameter), particle shape (aspect ratio), aggregate properties



New combined CFD-DEM strategy to track the transport of differently shaped objects

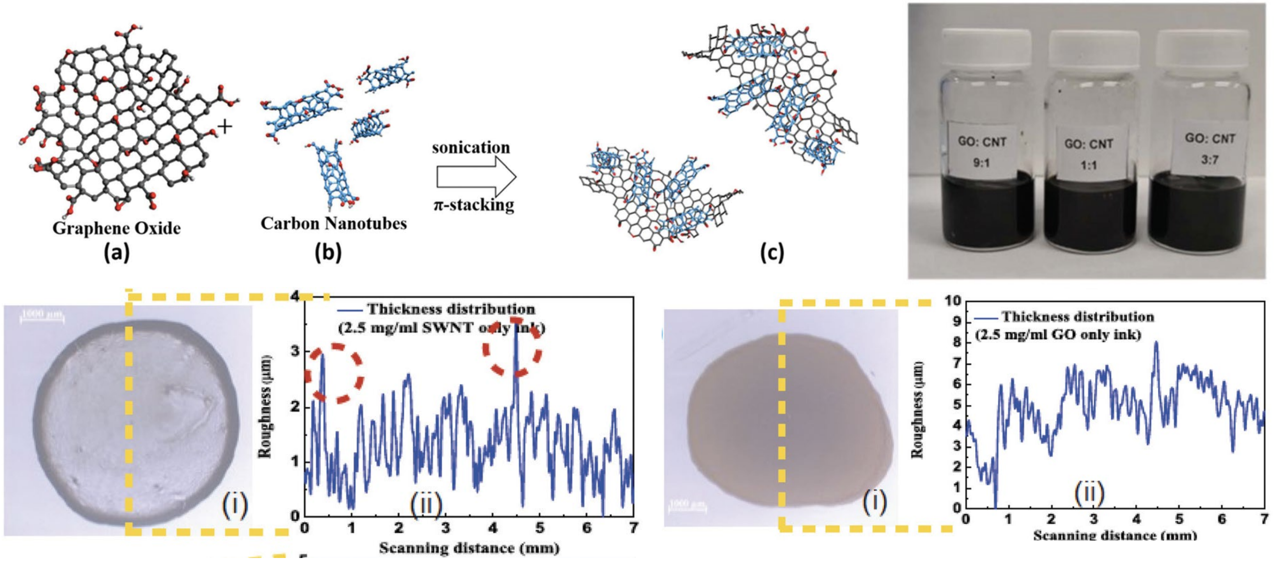


Time-dependent flow-driven migration of a cluster of (i)spherical particles and (ii) ellipsoidal particles.

Work supported by NCMS

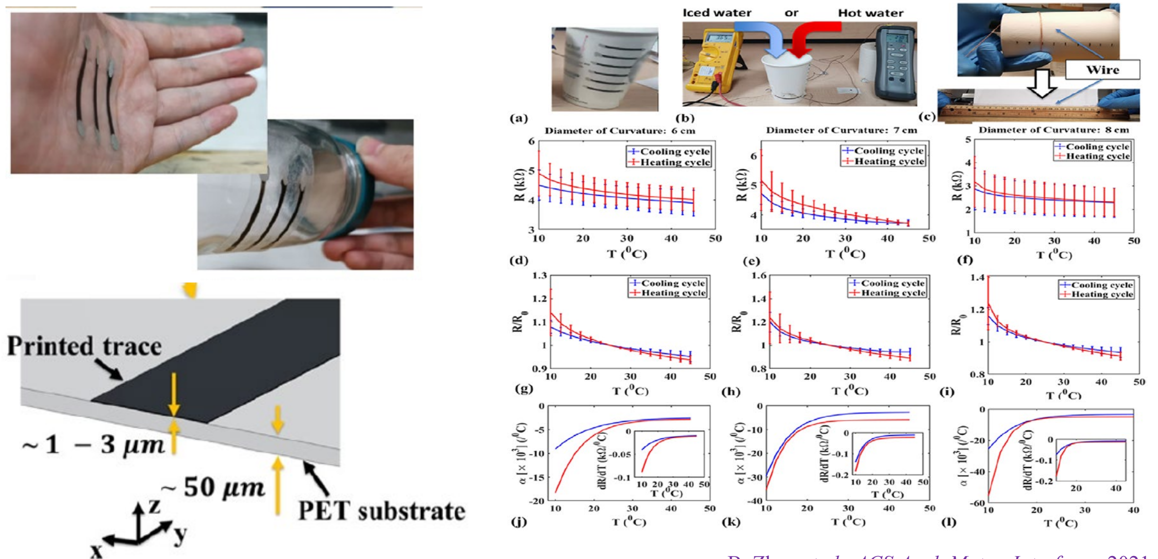
New CNT-based Inks for Fabricating Sensors and Antennae

Ink Fabrication and Shape-Based Printability



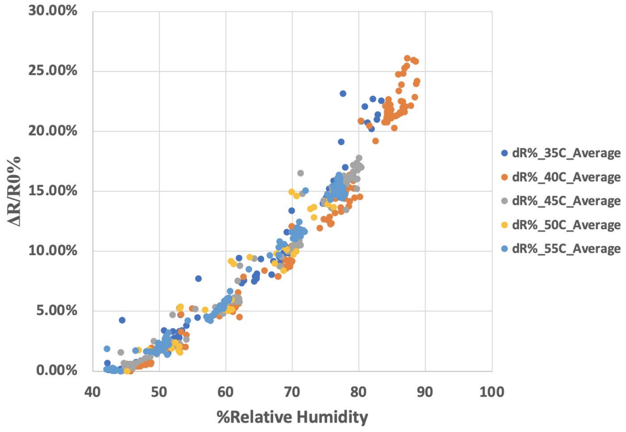
B. Zhao *et al.*, *Nanoscale*, 2019 (work supported by NAWCAD)

Highly sensitive, Ultra-thin Printed CNT-GO Temperature Sensor

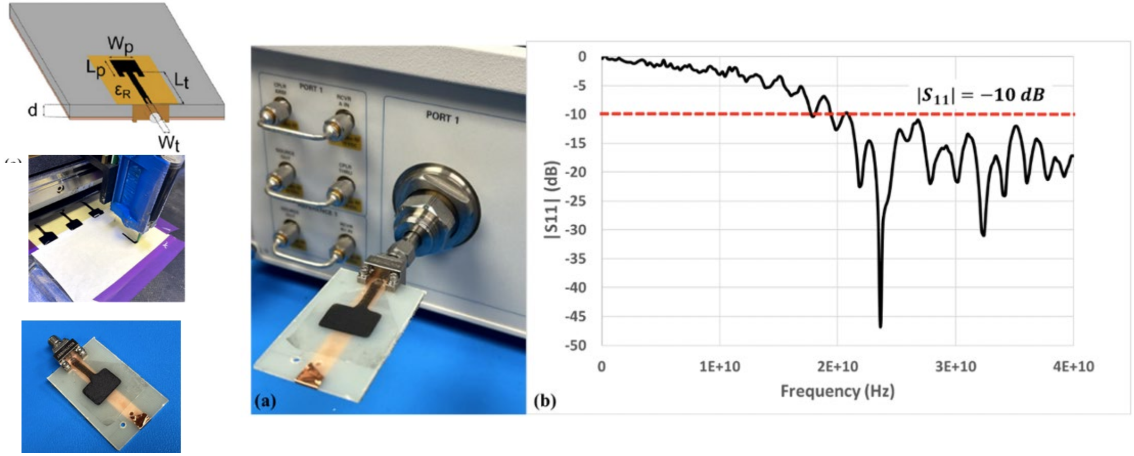


B. Zhao *et al.*, *ACS Appl. Mater. Interfaces*, 2021

Printed CNT-GO Ink Based Humidity Sensors

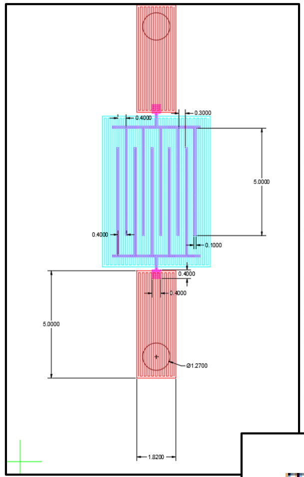


Printed CNT-GO Ink Based High Bandwidth Patch Antenna

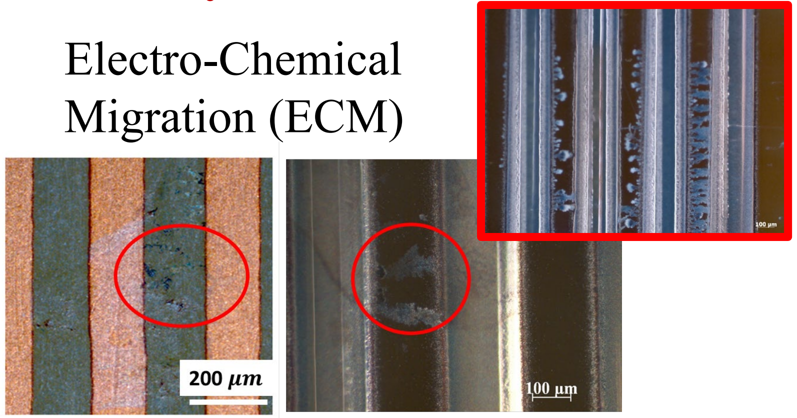


PHE Reliability Testing for Printed Ag-NP Traces

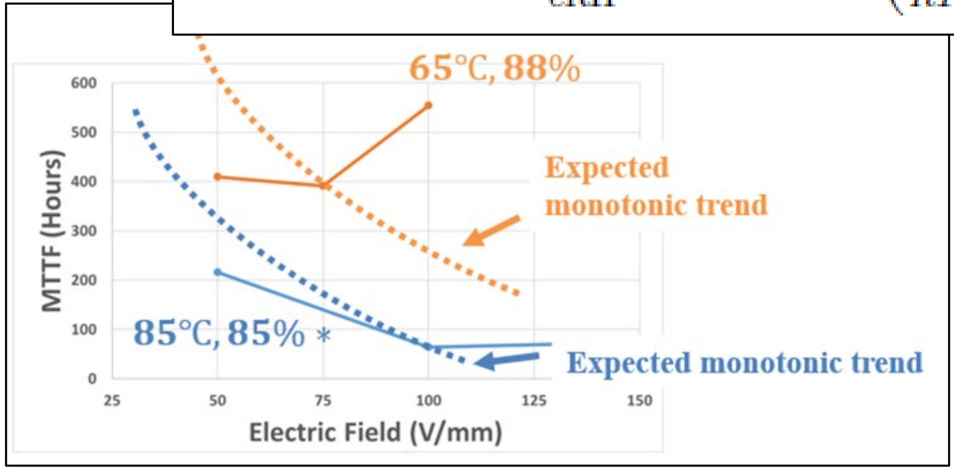
Temperature-Humidity-Bias:



Electro-Chemical Migration (ECM)

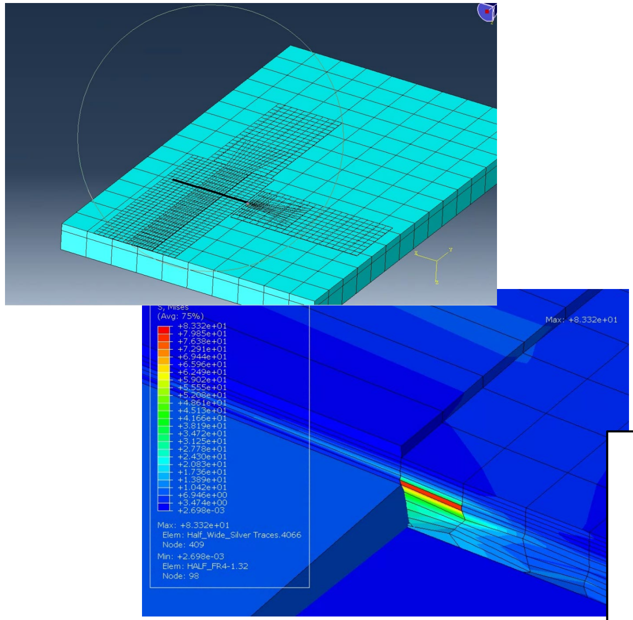


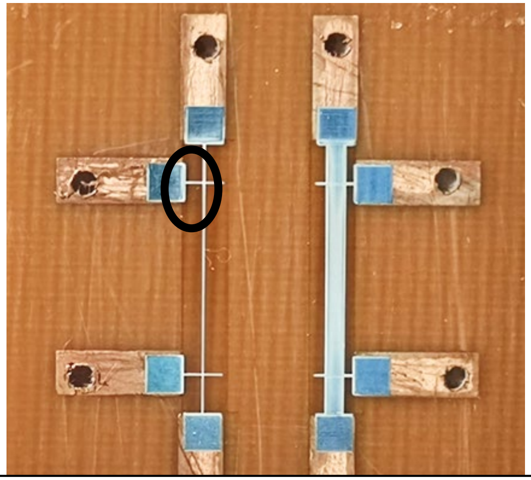
$$\mathrm{TTF} = nF \times \frac{m_0}{M} \times \beta \times \mathrm{f}(V) \times \frac{(1-\mathrm{RH})\,[1+(c-1)\mathrm{RH}]}{c\mathrm{RH}} \times \exp\left(\frac{E_\sigma}{RT}\right)$$

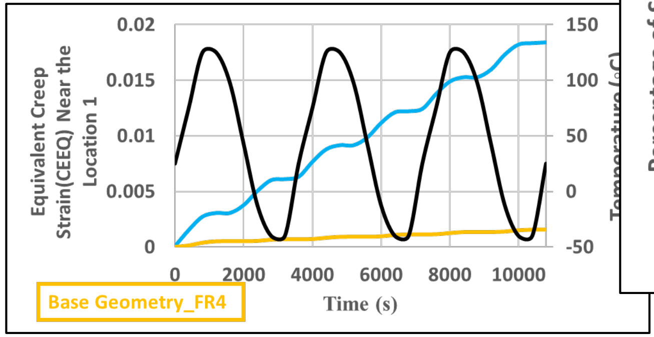


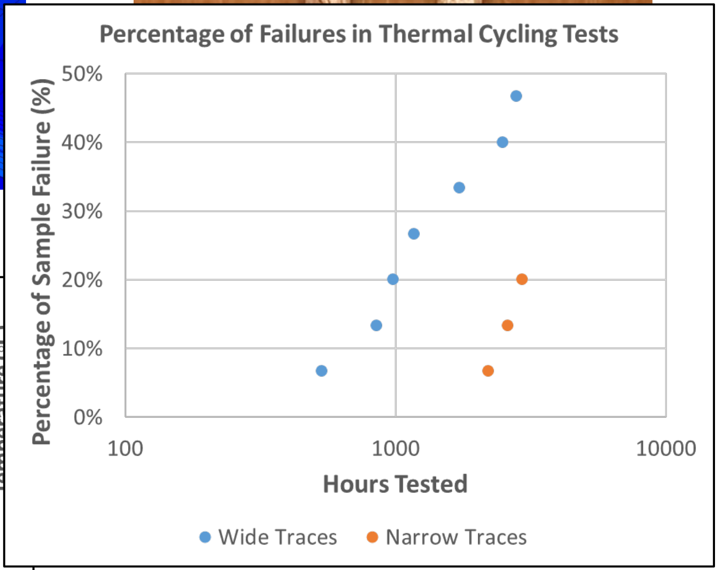
Thermal Cycling:

FR4, Kevlar, Ceramic Substrates





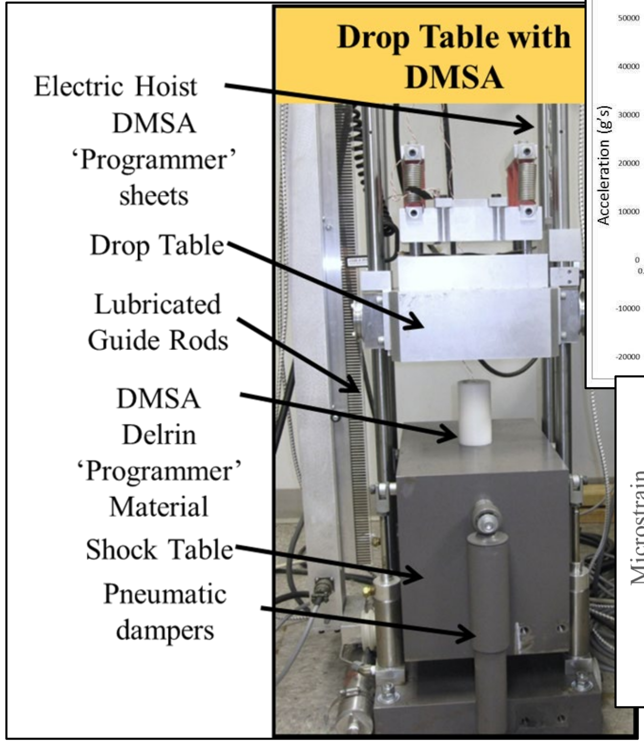


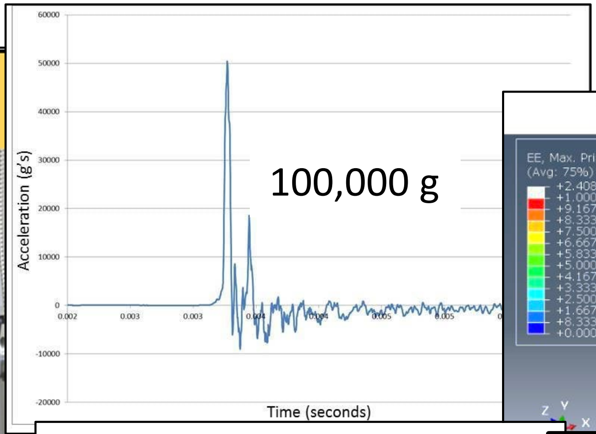


Qualification of 2D & 3D Printed Hybrid Electronics (PHEs) under Extremely High Acceleration

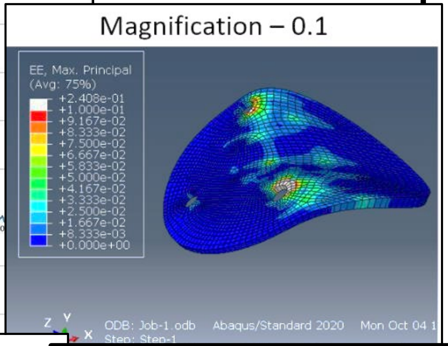
Objectives and Deliverables:

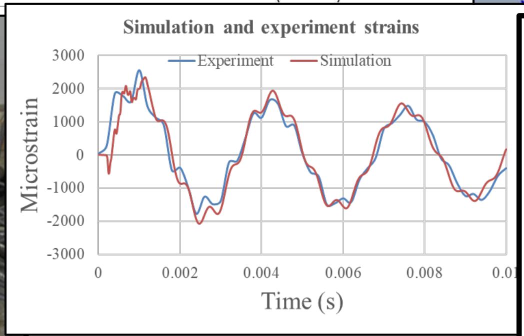
- **Phase 1**: Test results and mechanistic simulations of Drop Test at 30K Gs on existing drop tower
- **Phase 2**: Scale Phase 1 tasks to 50 K Gs and 100 K Gs

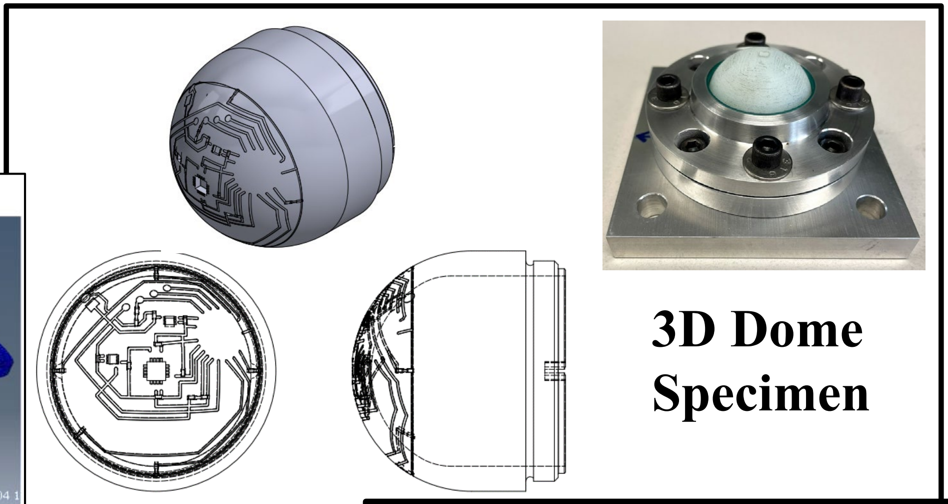


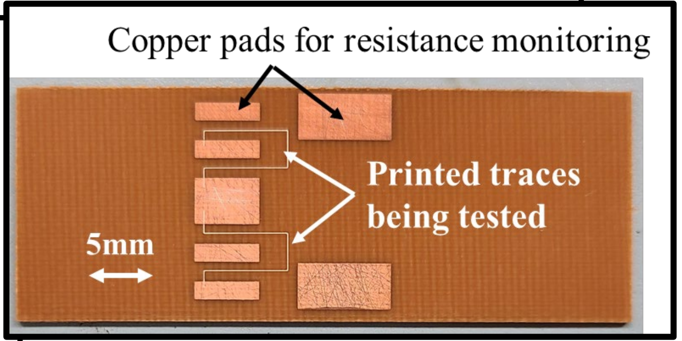


Drop Simulations



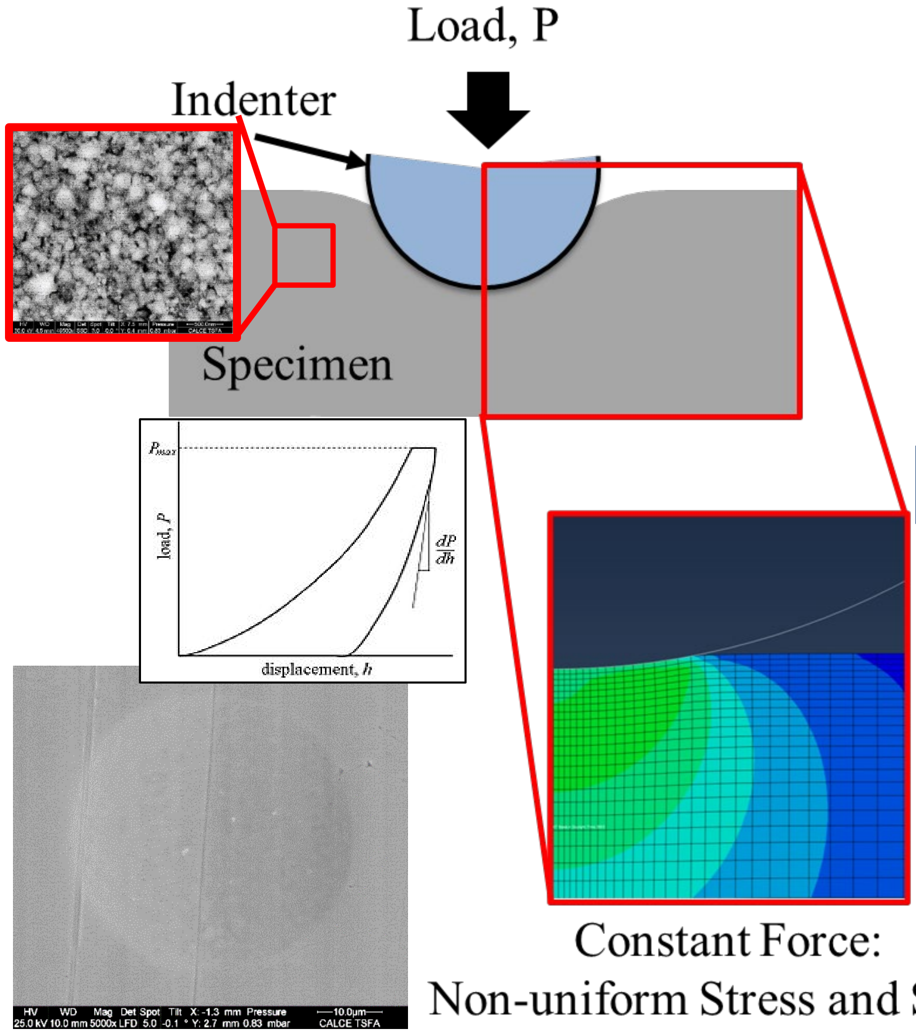






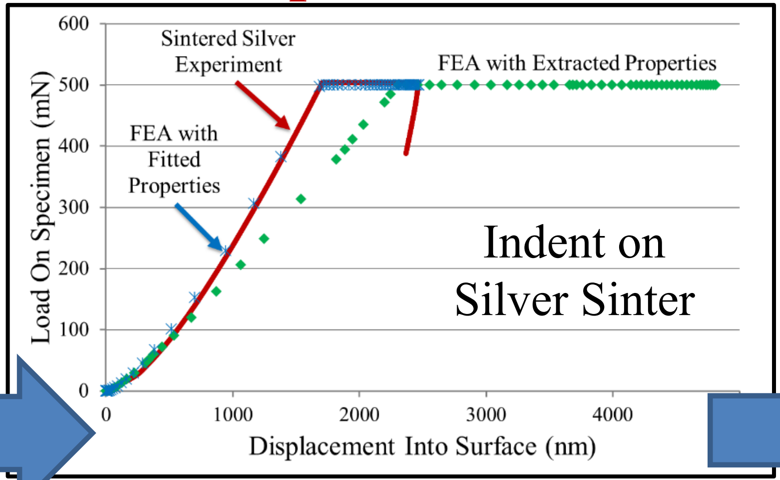
Material Metrology: Viscoplastic Properties of Ag Ink

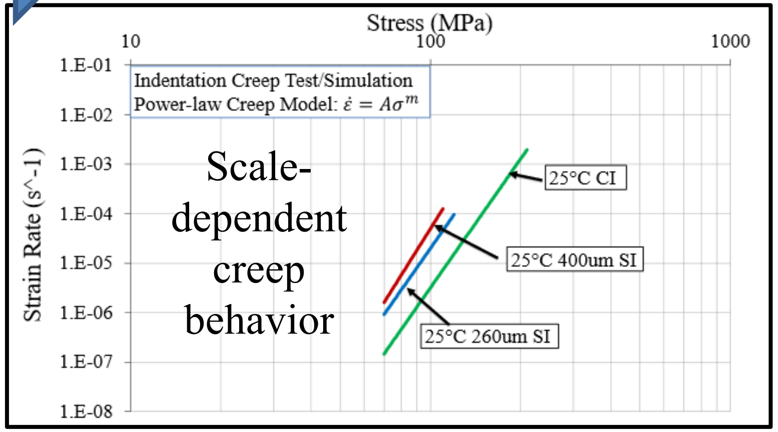
Indentation and Modeling



Constant Force:
Non-uniform Stress and Strain

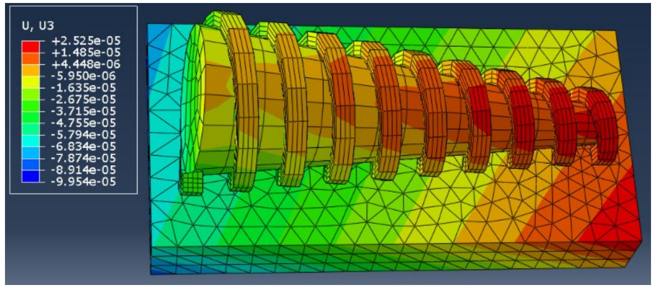
Elastic, Plastic, and Creep Parameters





Applications

Thermo-mechanical model of printed inductors to assess stresses caused by accelerated temperature cycling for reliability testing



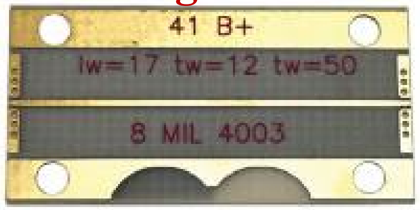
Extracted viscoplastic properties are needed for reliability simulations of printed electronic components.

Additive Repair, Reliability and Ruggedization of RF Circuitry

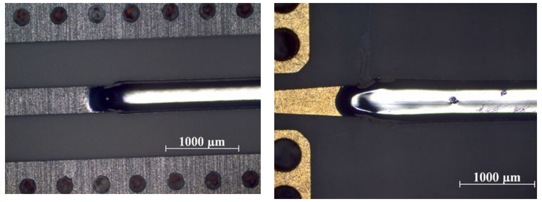
NextFlex 6.2

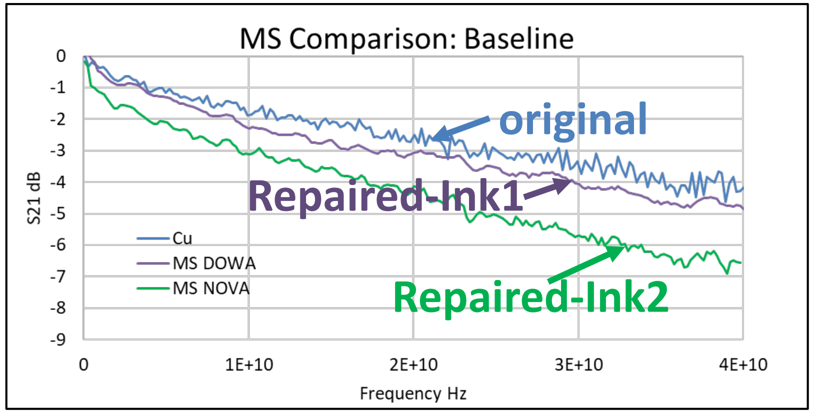
Microstrips and Coplanar Wave Guides

Original

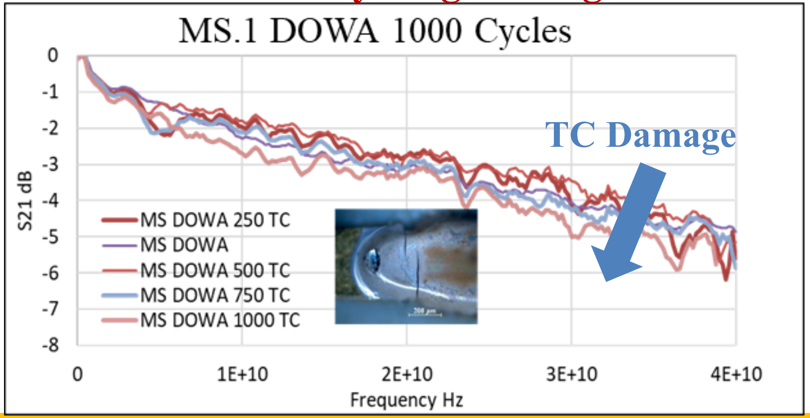


Additively Repaired

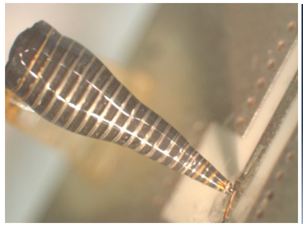


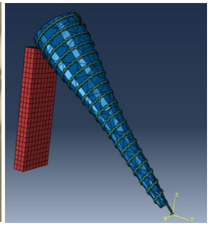


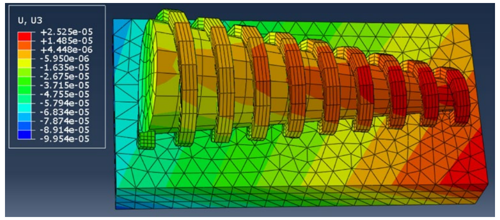
Thermal Cycling Damage



Printed Conical Spiral Inductors

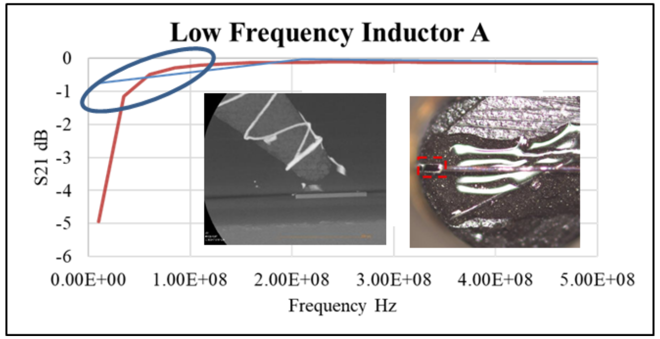




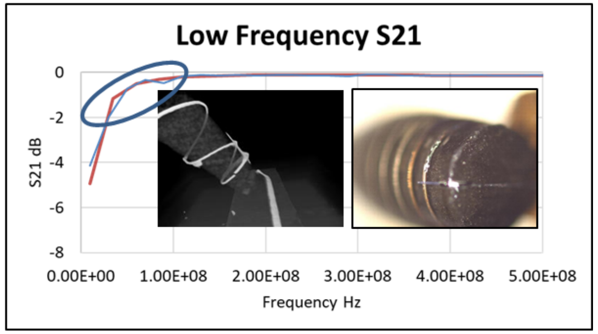


RF Damage Diagnostics & Additive Repair

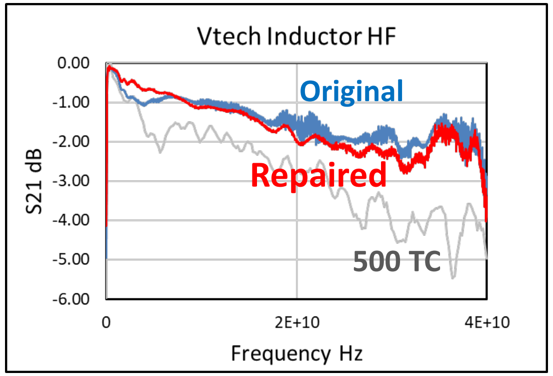
Handling Damage: Before repair



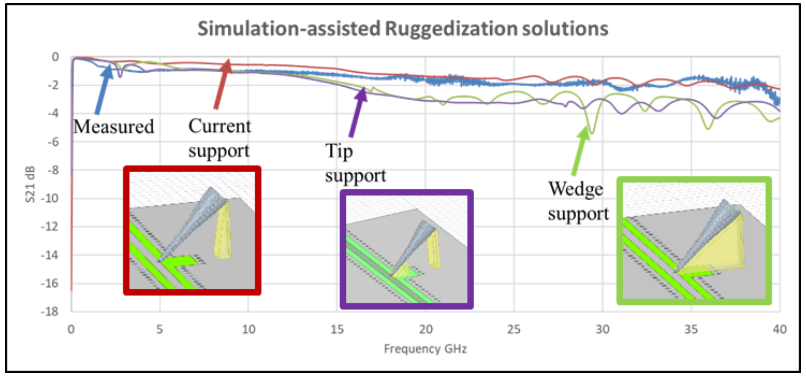
Handling Damage: After repair



Thermal Cycling Damage



RF Design Ruggedization Assessment



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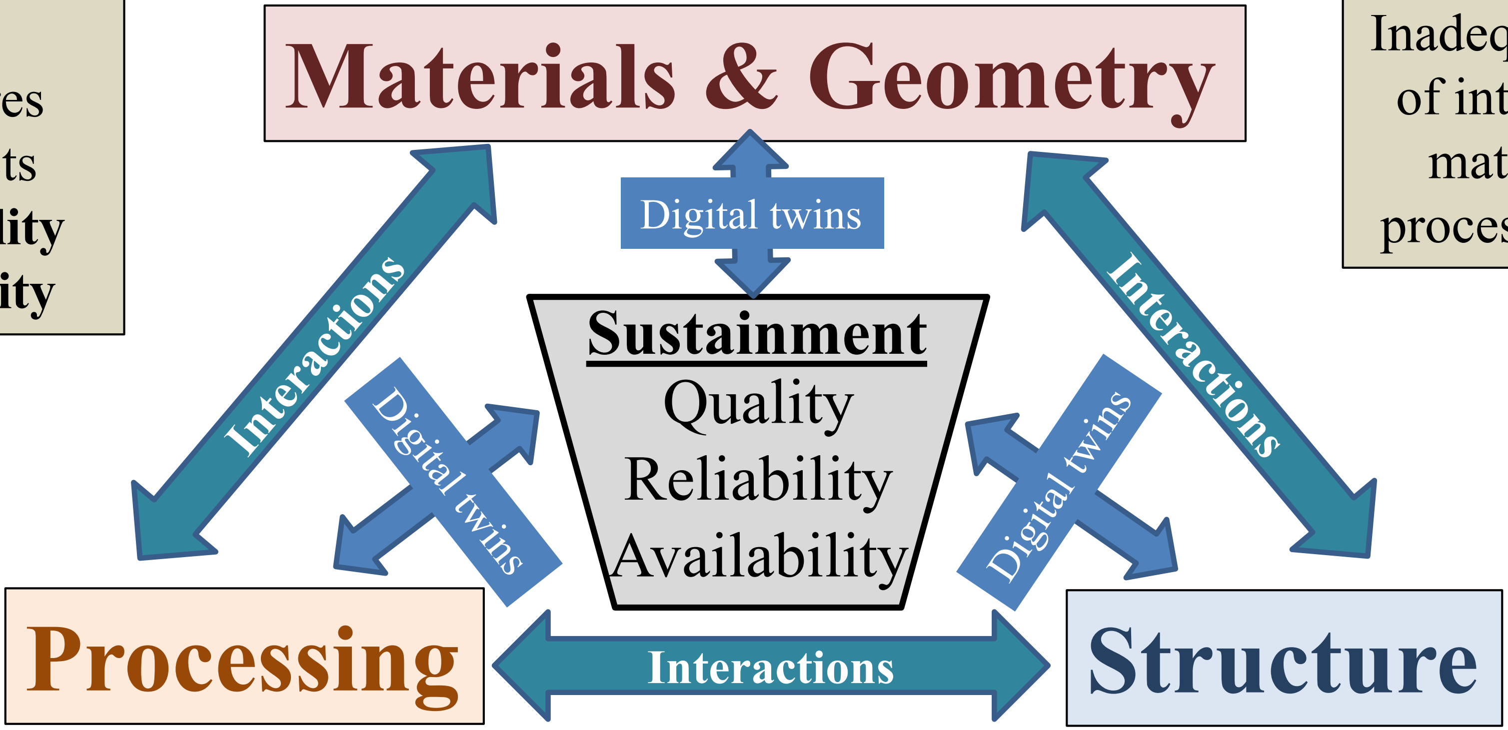

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New Reliability Challenges:
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Overspray
Agglomeration
Porosity
Micro-cracks
Interfacial defects
Residual stresses