Additive Manufacturing Technologies for Aerospace Applications

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Materials and Structures Division

Exchange Meeting
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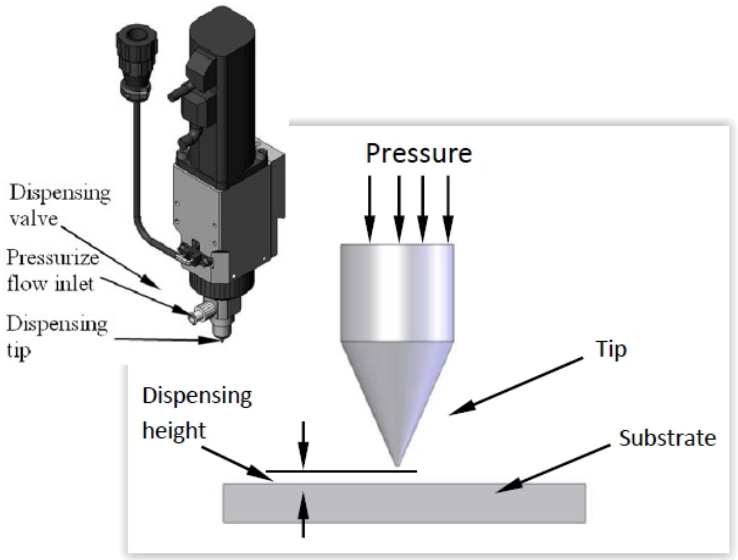
Outline

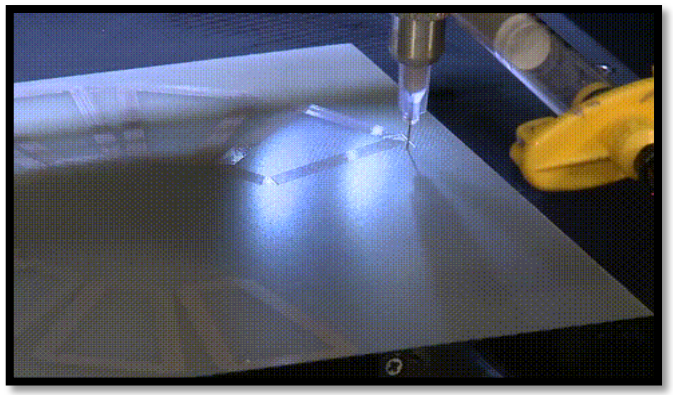
- Applications and NASA Strategic Thrusts
- Additive manufacturing capabilities
- Component applications

Additive Manufacturing Technologies

Direct Write Printing

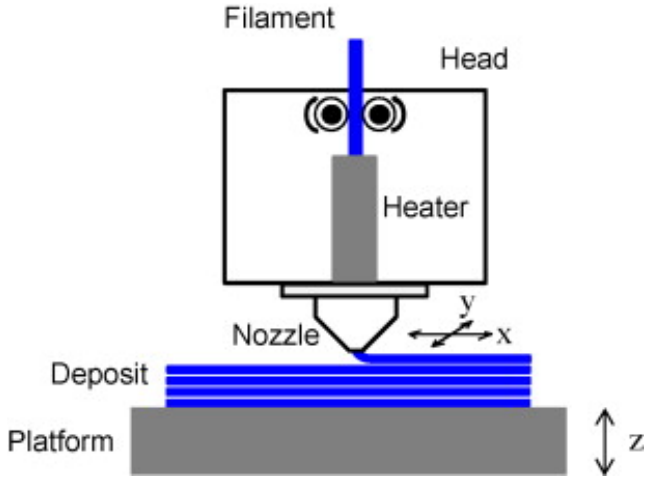
Controlled dispensing of inks, pastes, and slurries.

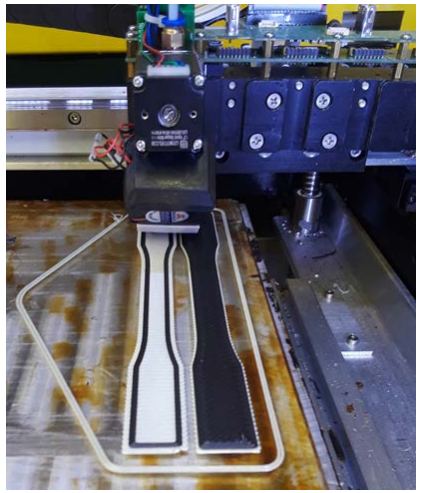




Fused Deposition Modeling

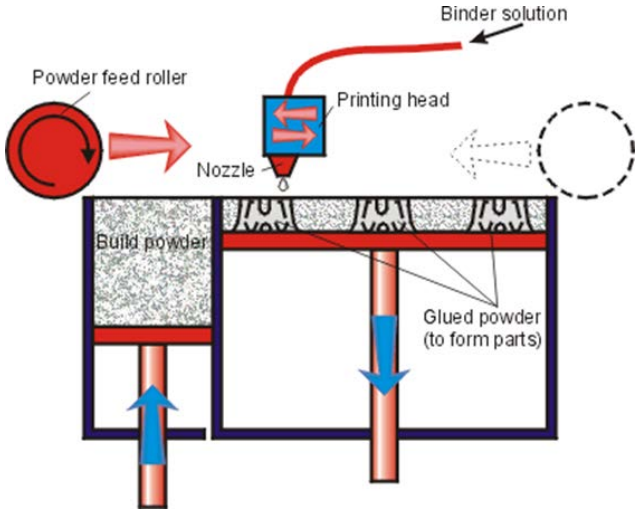
Plastic is heated and supplied through an extrusion nozzle and deposited.

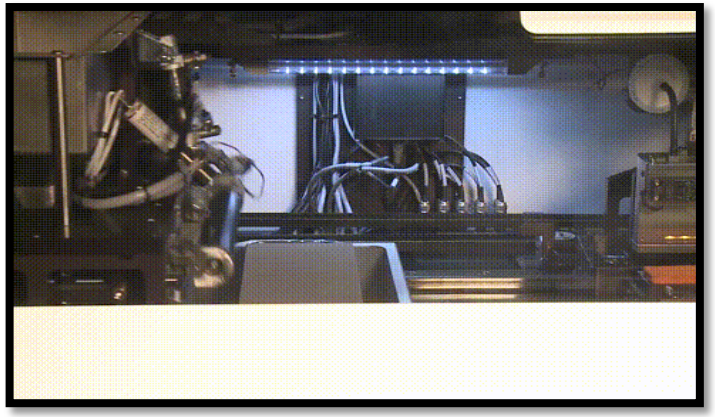




Binder Jetting

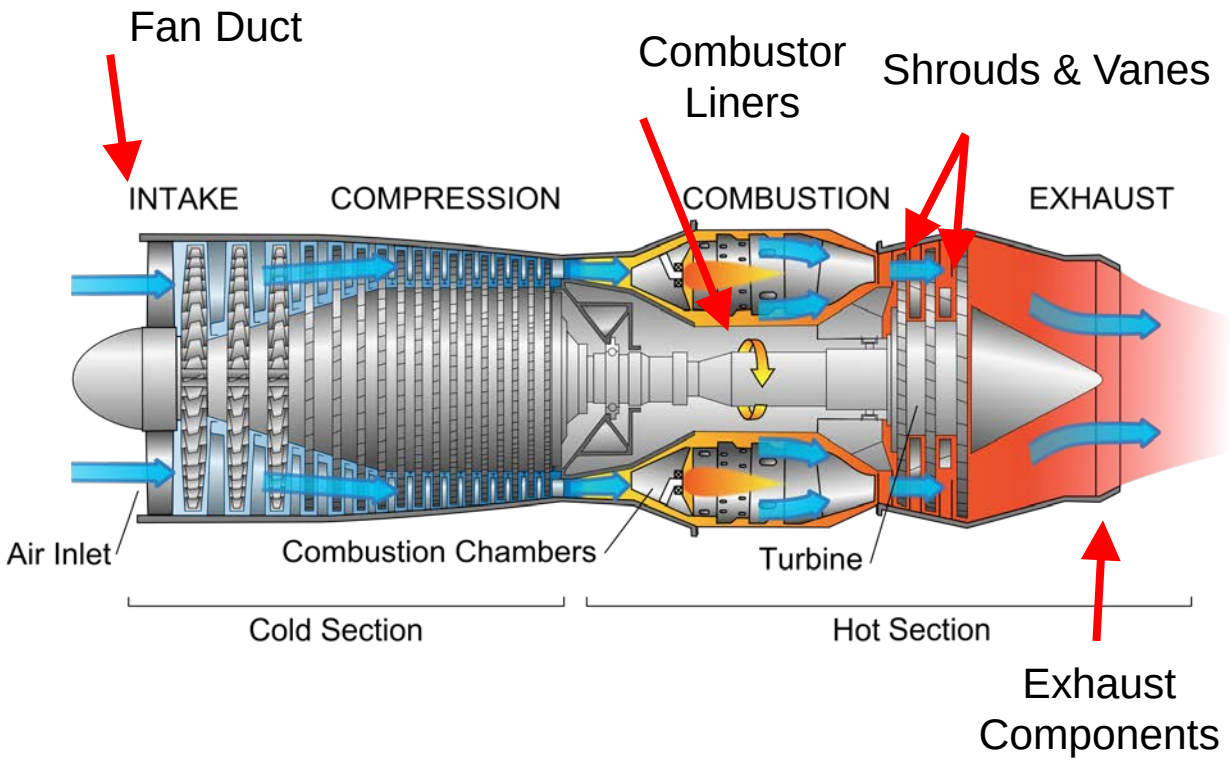
An inkjet-like printing head moves across a bed of powder and deposits a liquid binding material.



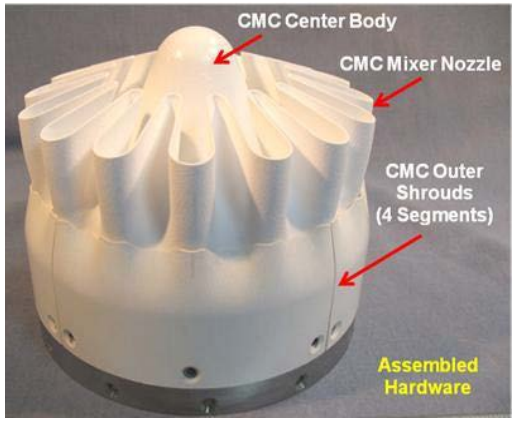


Components for Turbine Engine Applications

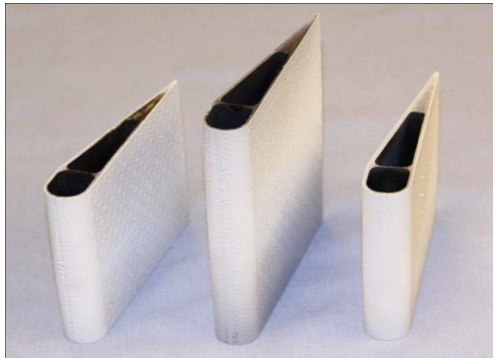
Turbine Engines -
Targeted Components (CMCs and PMCs)



NASA CMC Components from Conventional Fabrication Methods



Oxide/Oxide Mixer Nozzle



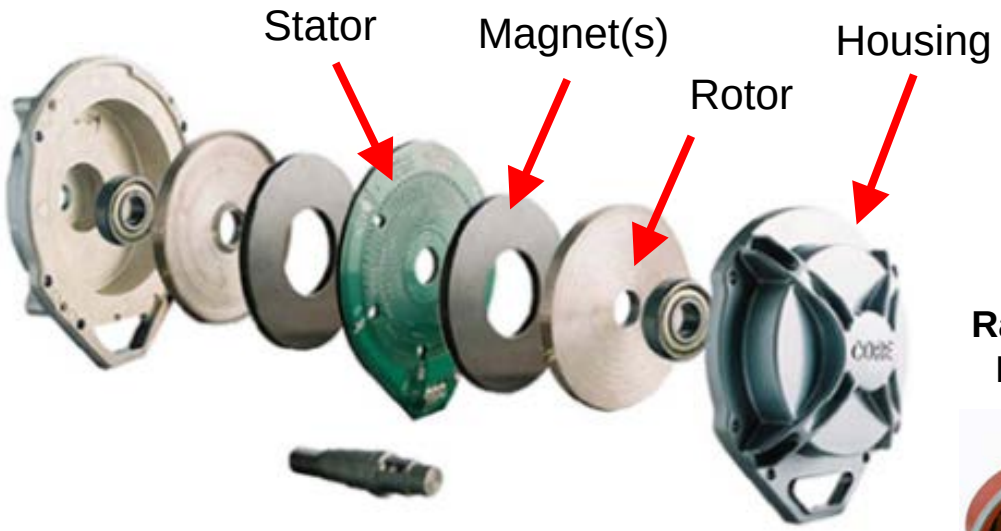
EBC Coated SiC/SiC Vanes

SiC/SiC Combustion Liners: Outer Liner and EBC Coated Inner Liner

Components for Electric Motor Applications

Electric Motors- Targeted Components (structural, functional, and electrical)

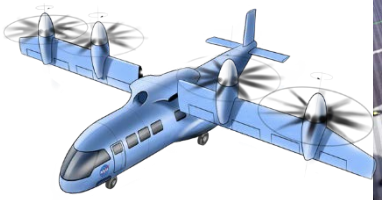
Axial Flux Machine



Radial Flux Machine

Electrified Aircraft

NASA 15-PAX tiltwing aircraft



Uber Elevate

NASA Aeronautics Research Six Strategic Thrusts

3. **Ultra-Efficient Commercial Vehicles**
   - Pioneer technologies for big leaps in efficiency and environmental performance
4. **Transition to Low-Carbon Propulsion**
   - Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

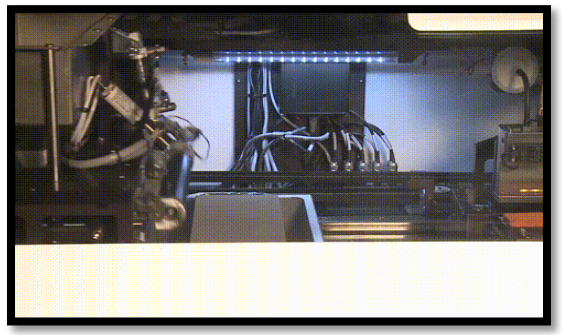
Achieve and exceed N+2 and N+3 goals for increased efficiencies and reduced emissions.

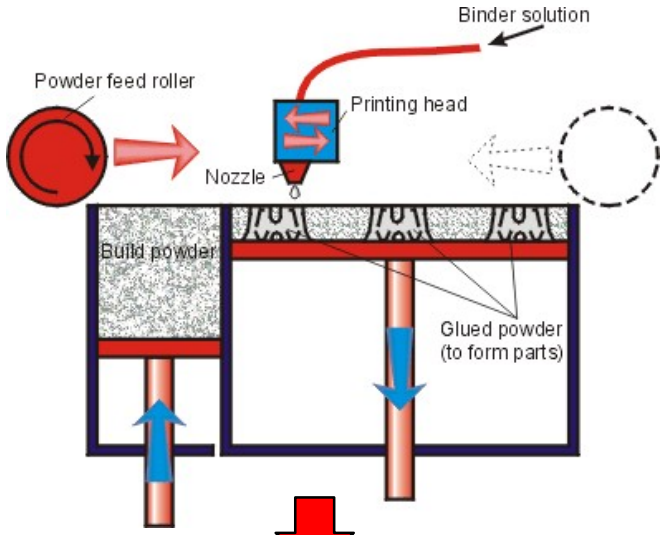
Binder Jet Additive Manufacturing of SiC

ExOne Innovent

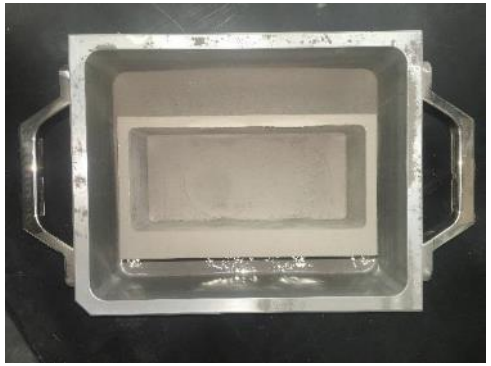
An inkjet printing head moves across a bed of powder and deposits a liquid binding material.

Powder Blending





De-powdering



Green part

Infiltration

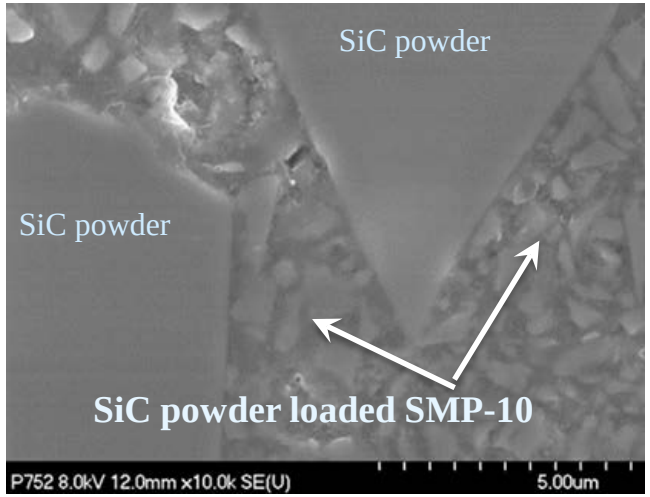
Final Part

Binder jet printing capability allows for powder bed processing with tailored binders and chopped fiber reinforcements for advanced ceramics.

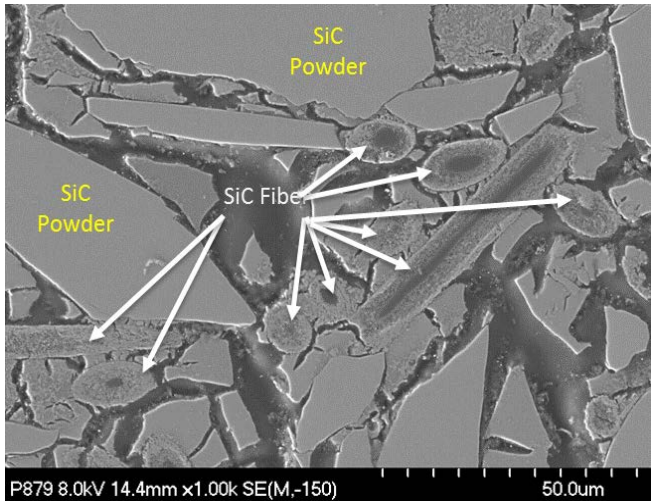
Binder Jetting of SiC Fiber / SiC Matrix Composites

ExOne Innovent

Constituents



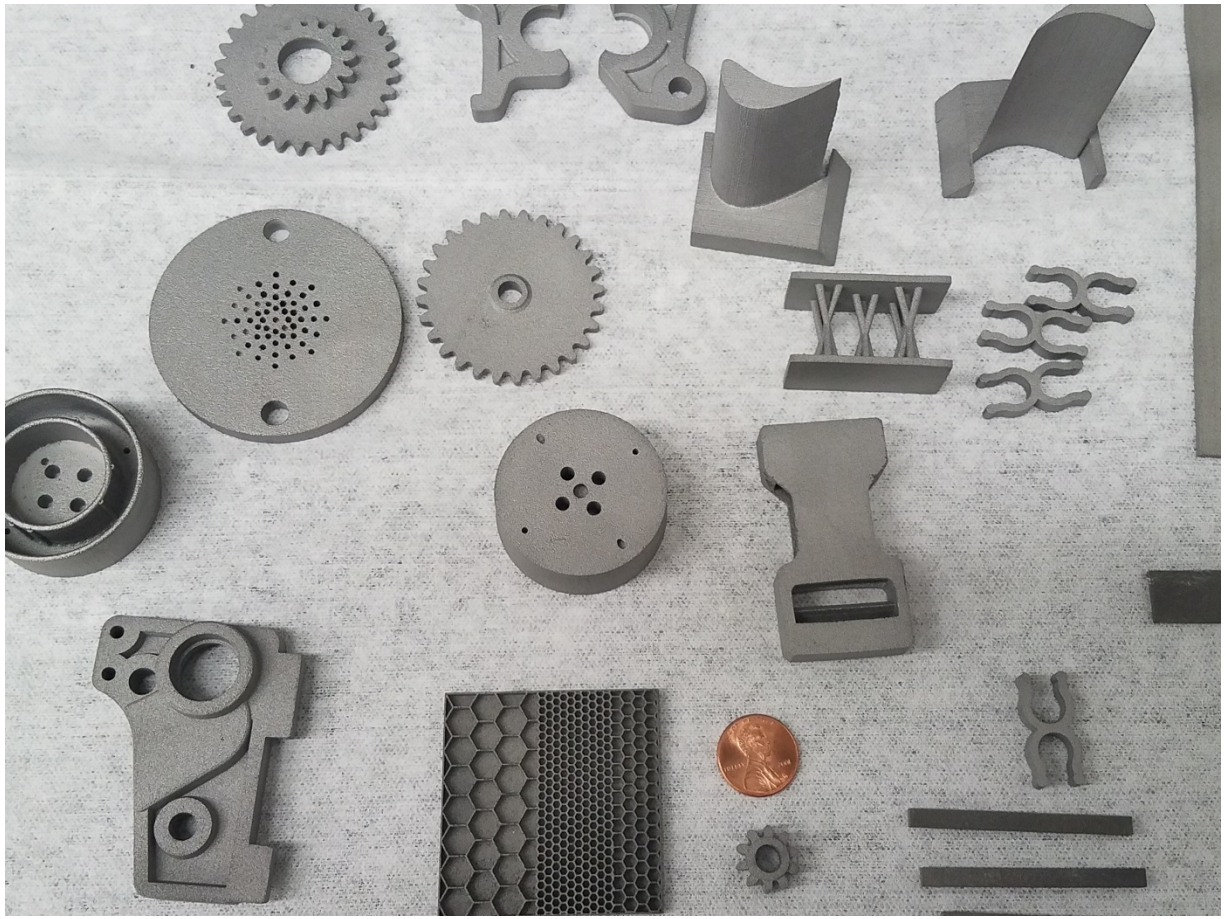
~70 µm long and ~7 µm in diameter

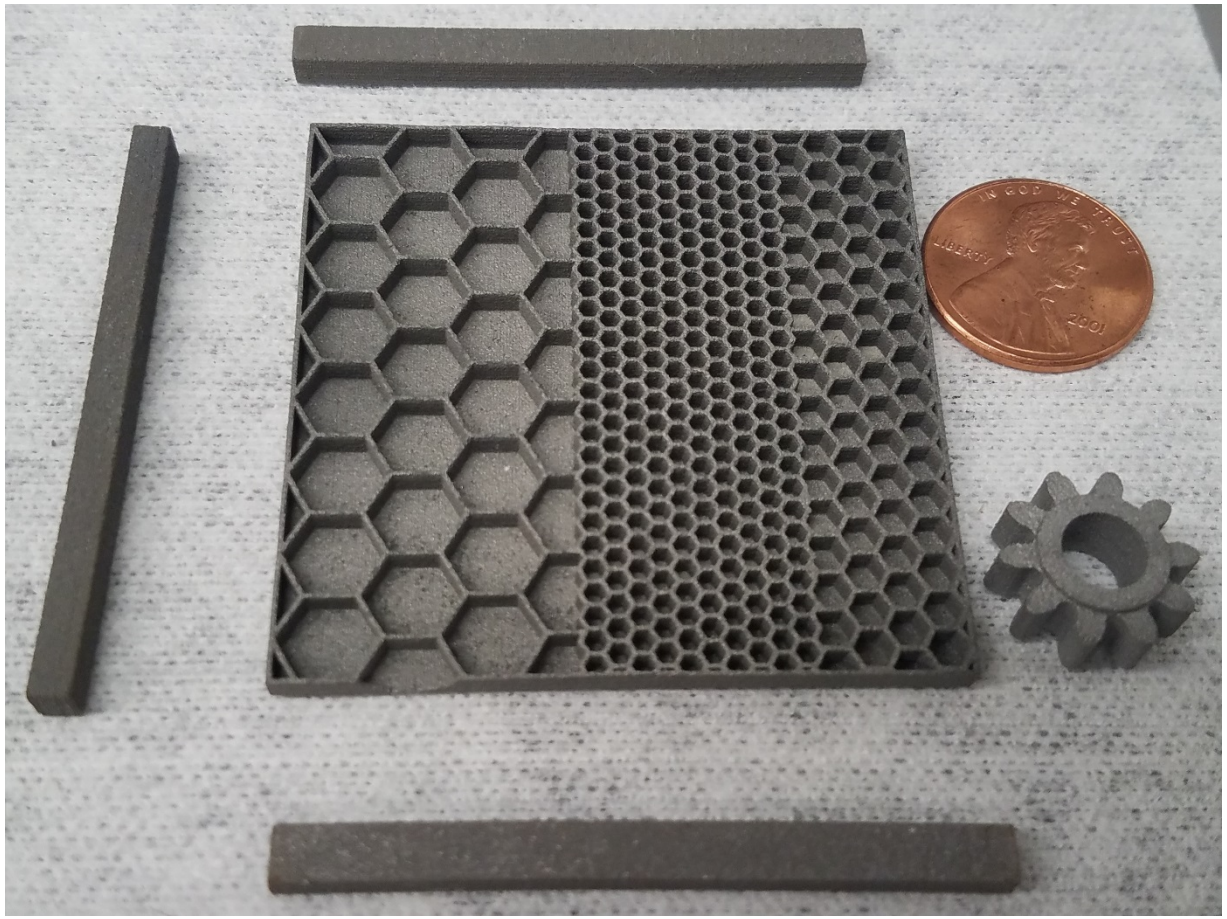


Fiber Reinforced Ceramic Matrix Composite

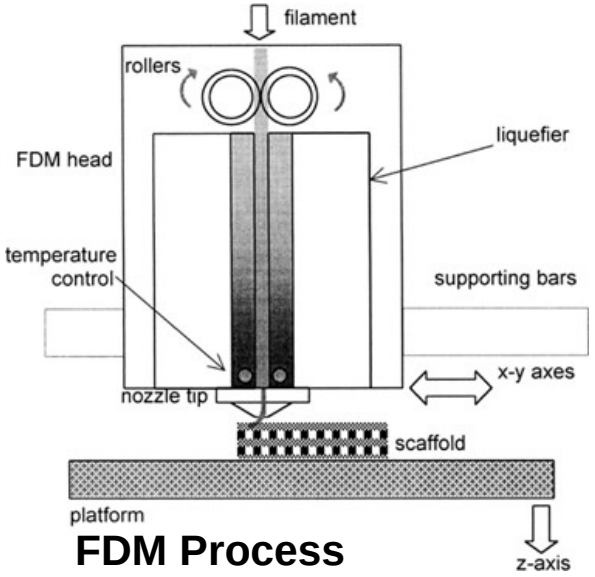
High pressure turbine cooled doublet vane sections.

Binder Jetting of Metallic Parts

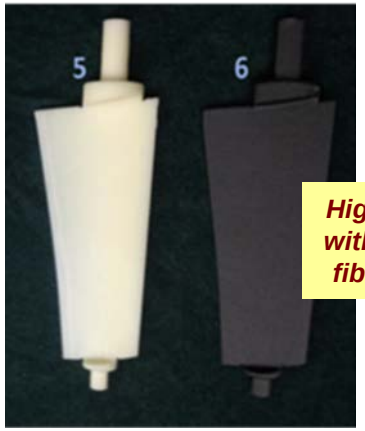




Demonstration of Polymer Components from FDM



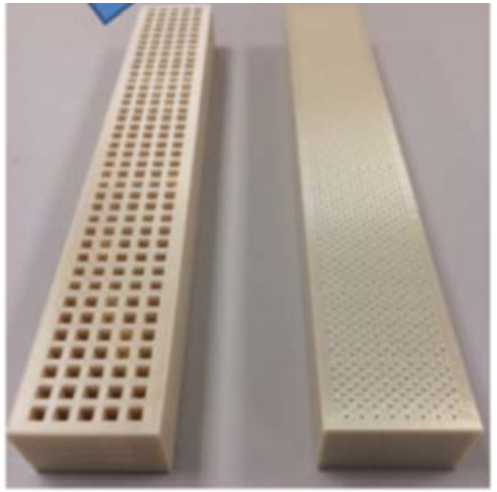
FDM Process



High temp. polymers with chopped carbon fiber reinforcement.

Inlet Guide Vanes from ABS and Ultem 1000

Engine Panel Access Door

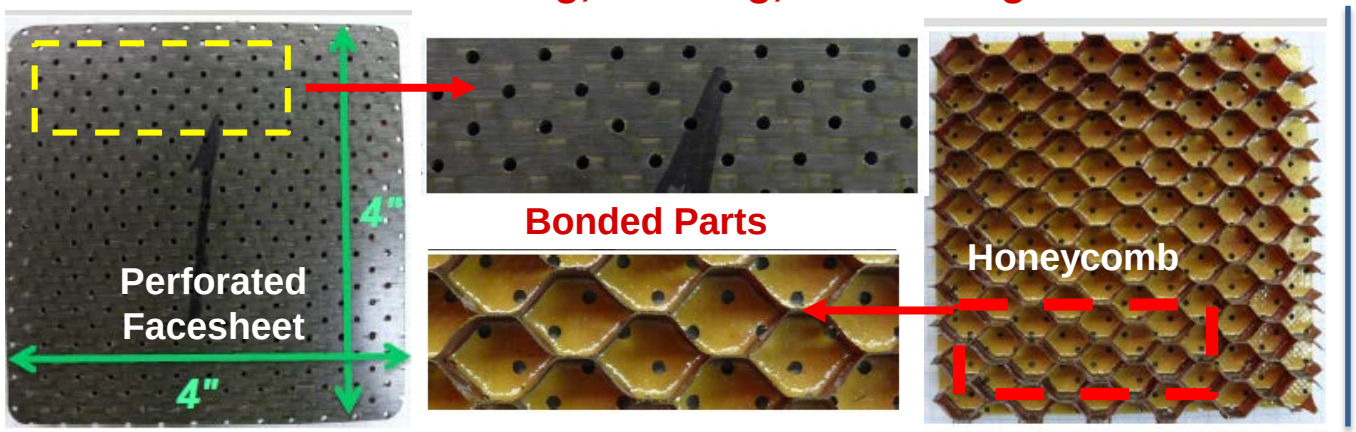


Acoustic Liner Test Articles

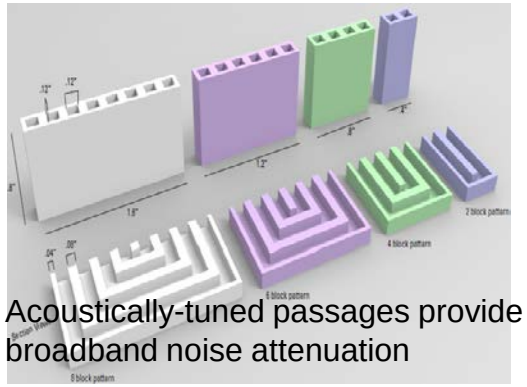
The focus is on unique structures, high temperature capability, and fiber reinforcement.

Additive Manufacturing by Fused Deposition Modeling Simplifies Engine Acoustic Liner Fabrication

Current manufacturing approach requires metal forming, bonding, and drilling

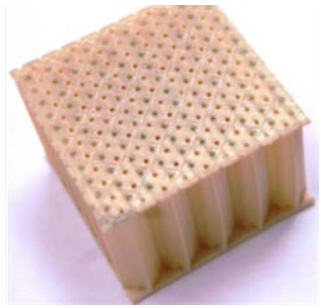


Advanced Liner Design from FDM

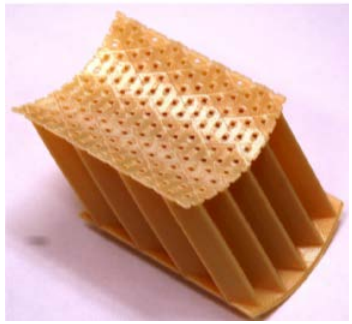


Acoustically-tuned passages provide broadband noise attenuation

Integral facesheet/honeycomb structures fabricated in one step using fused deposition modeling (FDM)

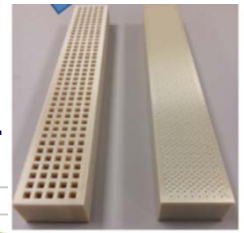


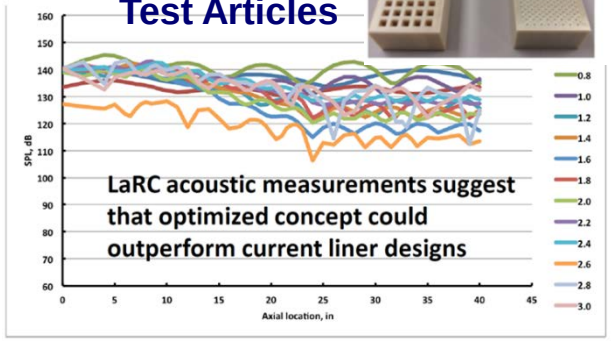
Standard Liner

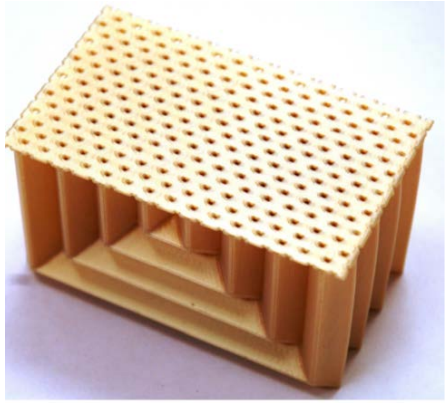


Complex Geometry

Acoustic Liner Test Articles







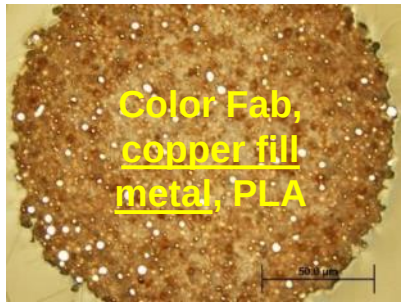
Fabricated with Ultem 9085 thermoplastic (T_g=367ºF), Application temperature of 200ºF

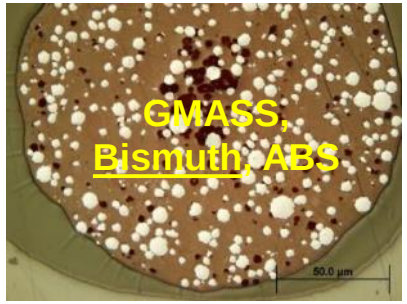
Optimized acoustic absorber would reduce engine fan noise

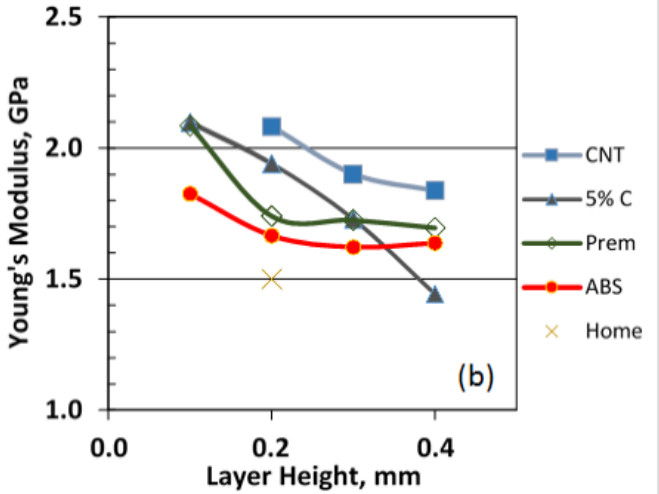
FDM of Composite Filaments for Multi-Functional Applications

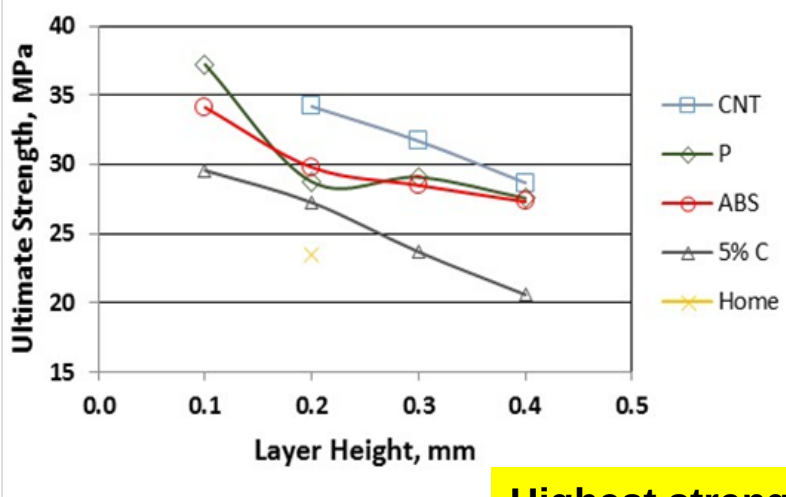
Potential Missions/Benefits:

- On demand fabrication of as needed functional components in space
- Tailored, high strength, lightweight support structures reinforced with CNT
- Tailored facesheets for functional properties, i.e. *wear resistance, vibration dampening, radiation shielding, acoustic attenuation, thermal management*

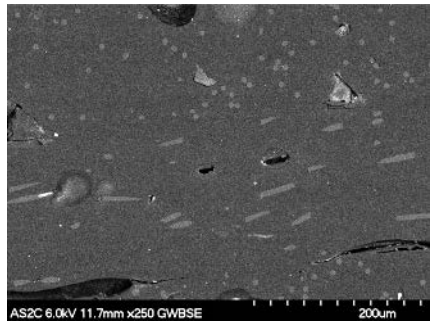




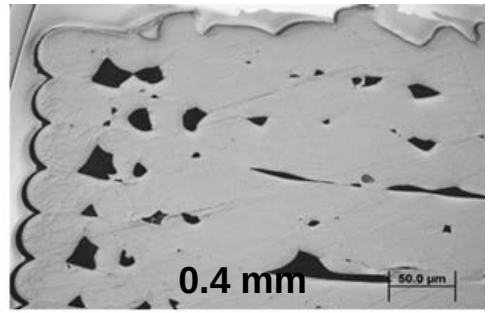


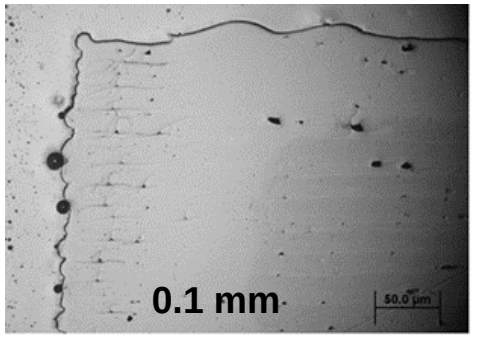


Filaments used: ABS-standard abs, P-premium abs, CNT-w/carbon nanotubes, C-w/chopped carbon, Home-lab extruded filament



C-Fiber Reinforced ABS Filaments





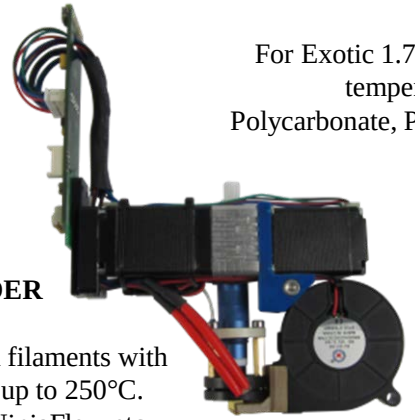
Effect of print layer height

Highest strength and modulus in CNT reinforced coupons versus standard ABS Coupons. Less porosity for lower print heights.

Hyrel Hydra 645 and Heads and Accessories on Hand (LMC)

Hyrel Hydra 645:
build volume
600x400x500mm X/Y/Z

MK1-250 EXTRUDER
Standard Hot Flow
For the most common 1.75mm filaments on the market with service temperatures up to 250°C.
ABS, Nylons, PLA, PETT, etc.

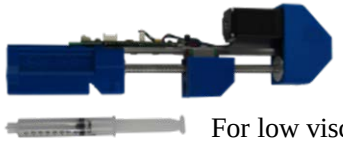


MK2-250 EXTRUDER
Flexible Hot Flow
For Flexible 1.75mm filaments with service temperatures up to 250°C.
BendLay, FilaFlex, NinjaFlex, etc

VOL-25 EXTRUDER
Warm Flow
For emulsifiable materials with service temperatures up to 100°C, such as waxes and glues.

MK1-450 EXTRUDER
Very Hot Flow
For Exotic 1.75mm filaments with service temperatures between 250-450°C.
Polycarbonate, PEEK, Ultem, Carbon Fiber.

ST1 ROUTER
Engrave, Cut, Route
For simple operations only possible with a spindle tool. *NOTE: you must supply your own fixturing.*
Paper, Wood, Metals (Drilling only), PCB (Routing), Acrylic

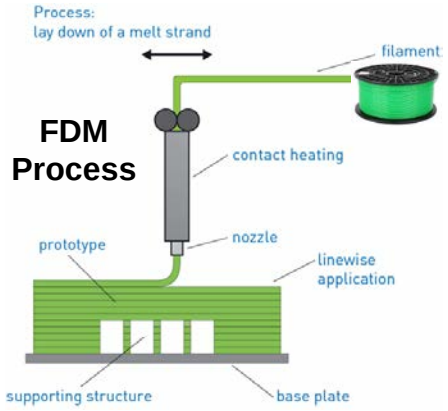


SDS-10EXTRUDER
Sterile, Disposable
For low viscosity, room temperature materials with 10cc syringes. Liquids, Gels, Biologicals, etc.

SDS-60 EXTRUDER
Sterile, Disposable
For low viscosity, room temperature materials with 60cc syringes. Liquids, Gels, Biologicals, etc.

QUIET STORM COOLING FAN
Additional, Directed Cooling
Programmable cooling where you want it.
Position, Program, Peace of Mind

Multi-Material Tensile Testing of Higher Temp. Ultem

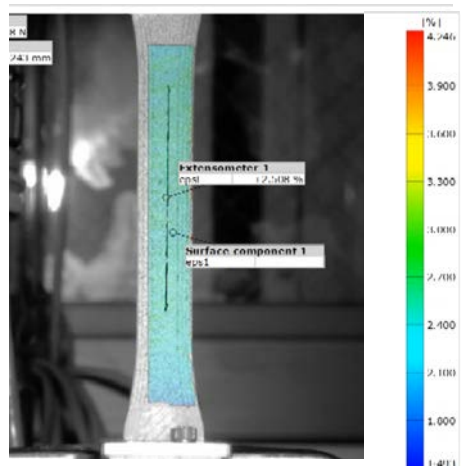


FDM Process

Hyrel Hydra 645

Multi-material print

Tensile Testing



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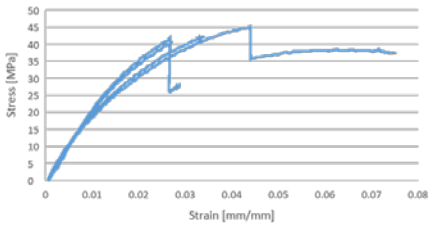
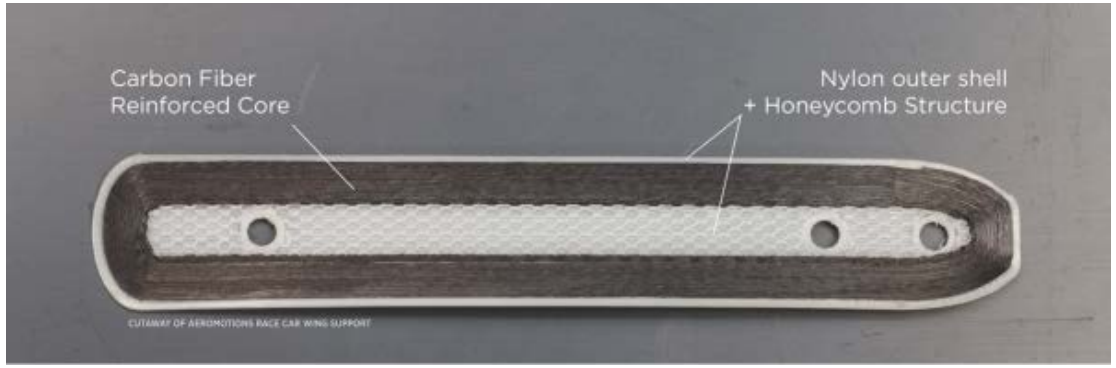
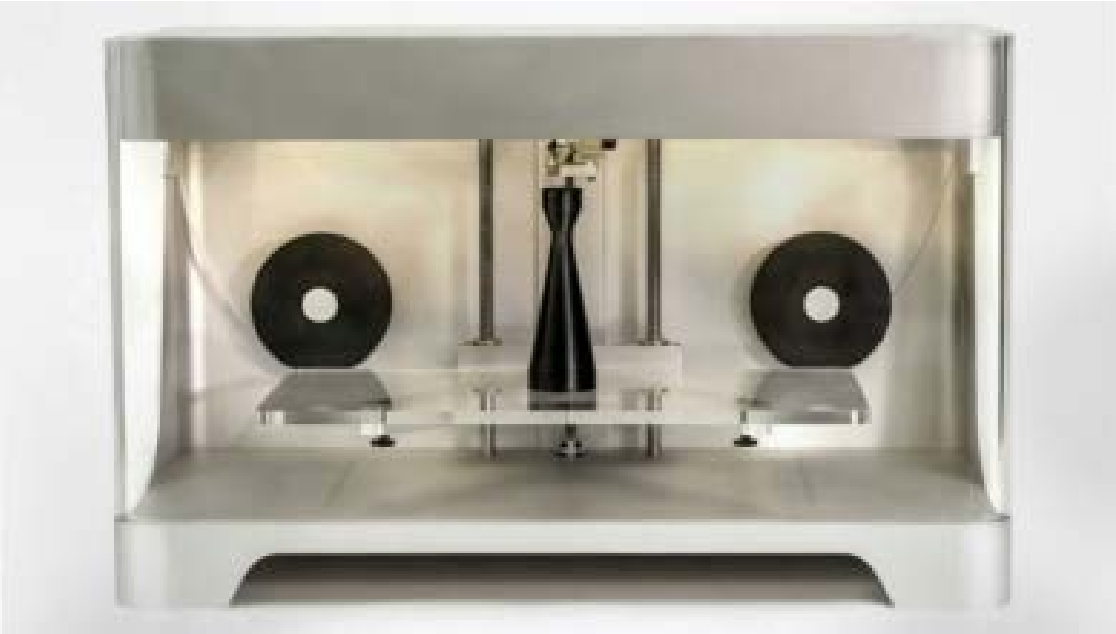
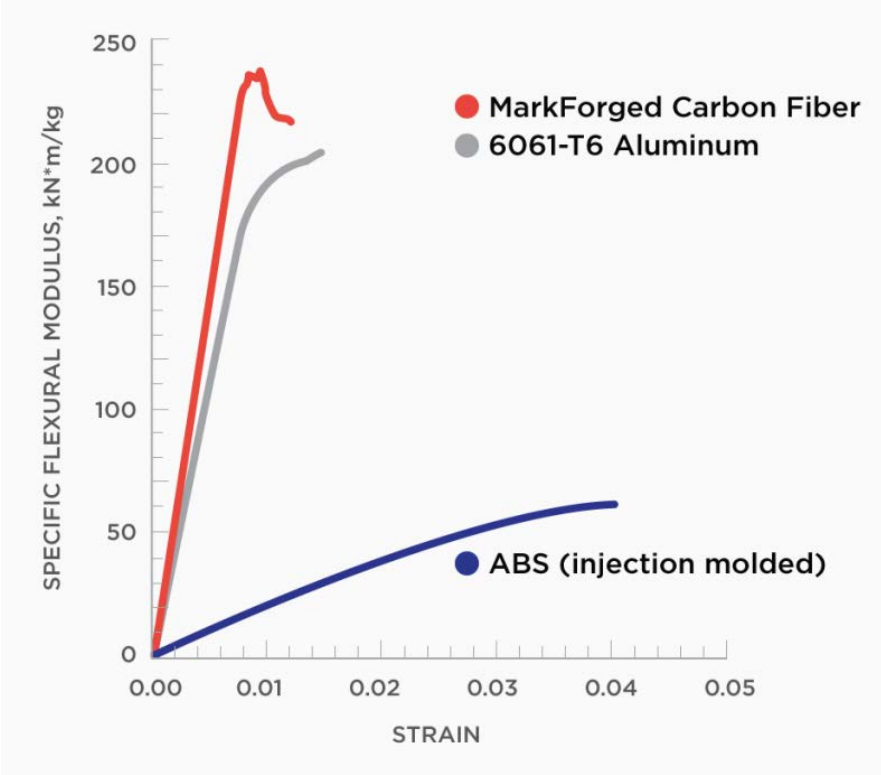


Mark Forged – 3D printing of Fiber Reinforced Parts





Two print heads: one for nylon and the other for fiber reinforced composite.

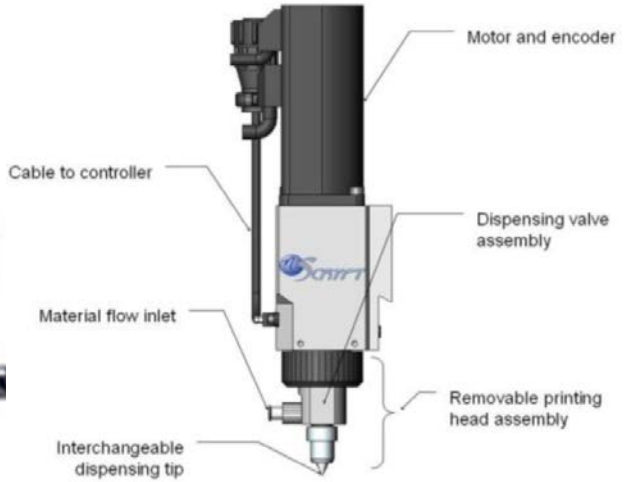


- **Higher strength-to-weight than 6061 Aluminum**
- **24X stronger than ABS**

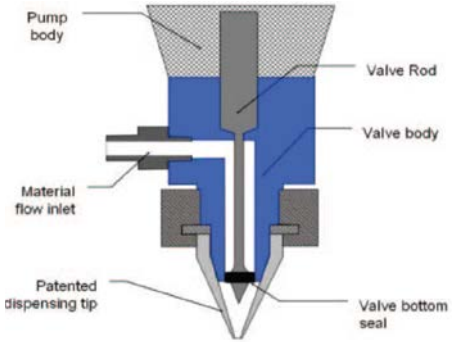
NScrypt Capabilities and Benefits

- Ability to host up to four separate materials and print on curved surfaces or print 3D structures.
- Motion control accuracy of ±5 microns and repeatability of ±2 microns in XY Micro-dispensing pump has volume control of dispensed materials of 100 picoliters.
- Ability to print a wide variety of ceramic pastes (structural and functional), electronic pastes, adhesives, solders, bio-materials.
- Direct writing with no contact or masks as for screen printing
- Clean starts and stops

NScrypt SmartPump

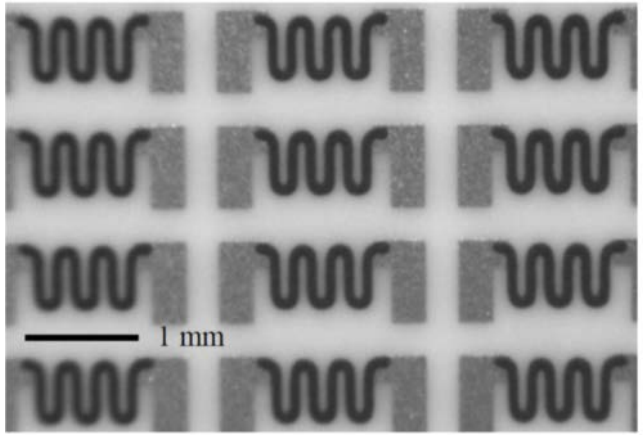


SmartPump Valve Assembly

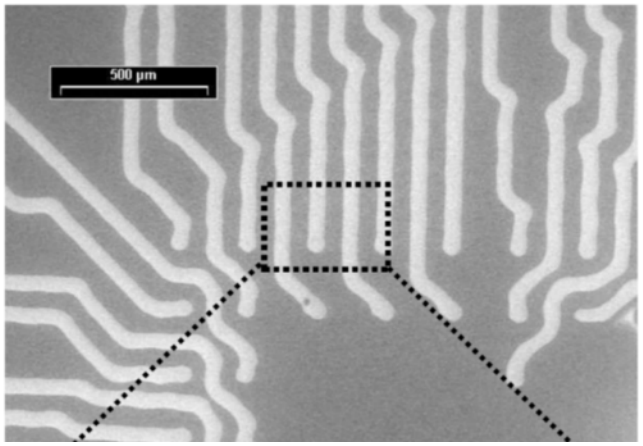


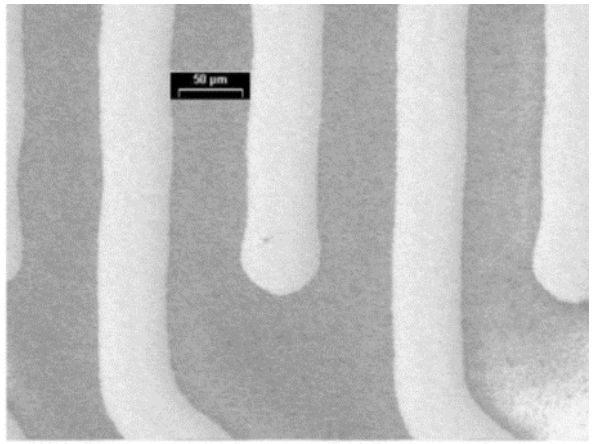
Ref: Chen, Xudong, et al. "Improved front side metallization for silicon solar cells by direct printing." *Photovoltaic Specialists Conference (PVSC), 2011 37th IEEE*. IEEE, 2011.

NScrypt Print Examples: Electronics



Resistors with 75µm line width and 200 µm pitches dispersed.

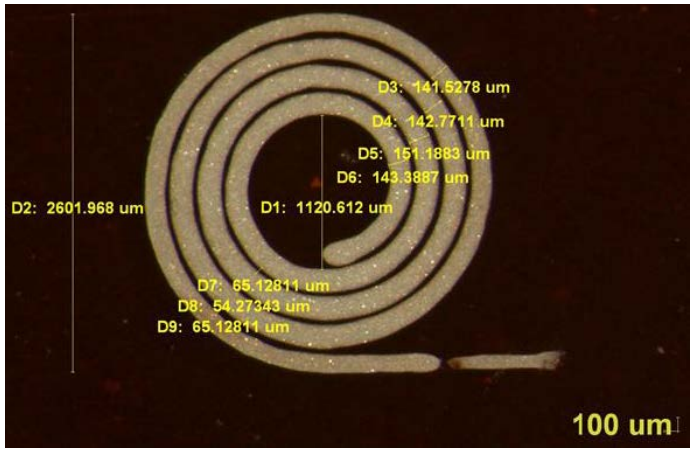




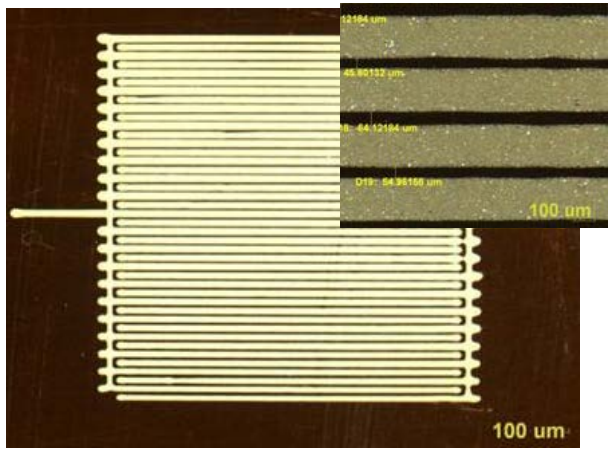
Conductors Dispensed by NScrypt.

Ref: B. Li, P. A. Clark, and K. H. Church. "Robust direct-write dispensing tool and solutions for micro/meso-scale manufacturing and packaging." *ASME 2007 International Manufacturing Science And Engineering Conference*. American Society of Mechanical Engineers, 2007.

Ref: Dominguez, Ubaldo Robles. *3D printed impedance elements by micro-dispensing*. Diss. University of Texas at El Paso, 2013.



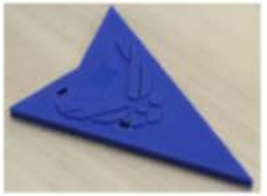
Planar spiral inductors



Close up of interdigitated capacitor and its line features

3D Printed Buried Electronics

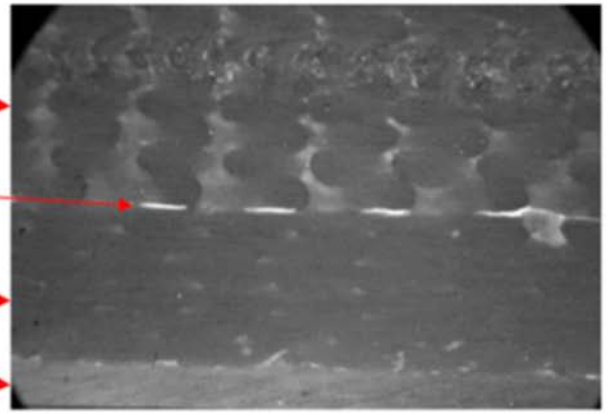
Solid, monolithic piece



Multi-material
- Clear polycarbonate
- Blue ABS
- Silver flake
- Carbon
- Dielectric
- Active device (silicon)
- Battery

Structure cut and sanded

Multi-pump
- Thermal plastics
- High viscosity paste



Printing of Multi-materials

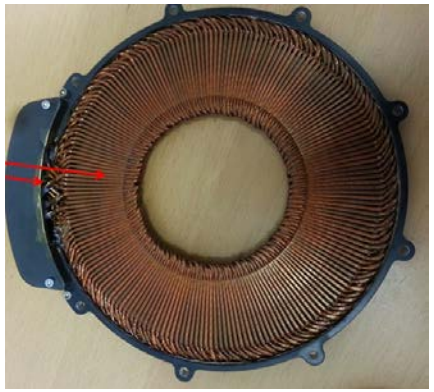
AM and Hybrid Approaches for Electric Motor Components

Electric Motors

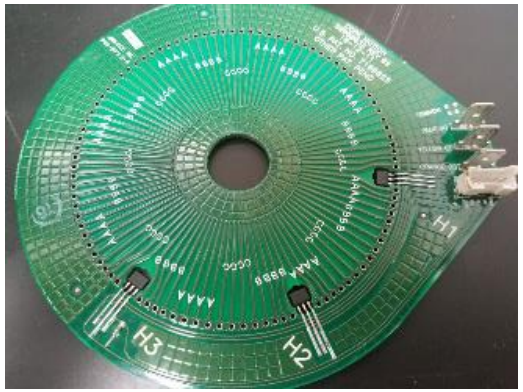
Components of a Commercial Axial Flux Motor

NASA Electric Motor with AM Components

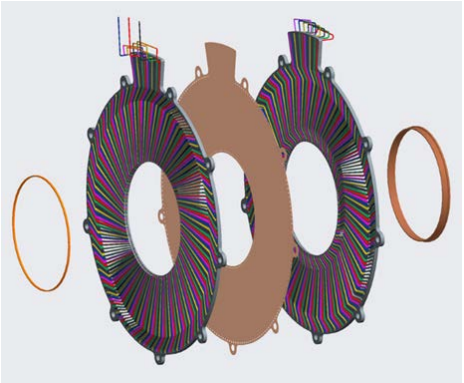
Stators



Litz Wire Coreless Stator



PCB Coreless Stator



Iron Core Stator with Direct Printed Coils

Stator Constituents:

- Conductor: copper, silver.
- Insulators: coatings, dielectrics, epoxy, high temp. polymer.
- Soft magnets (for cores): iron alloys.

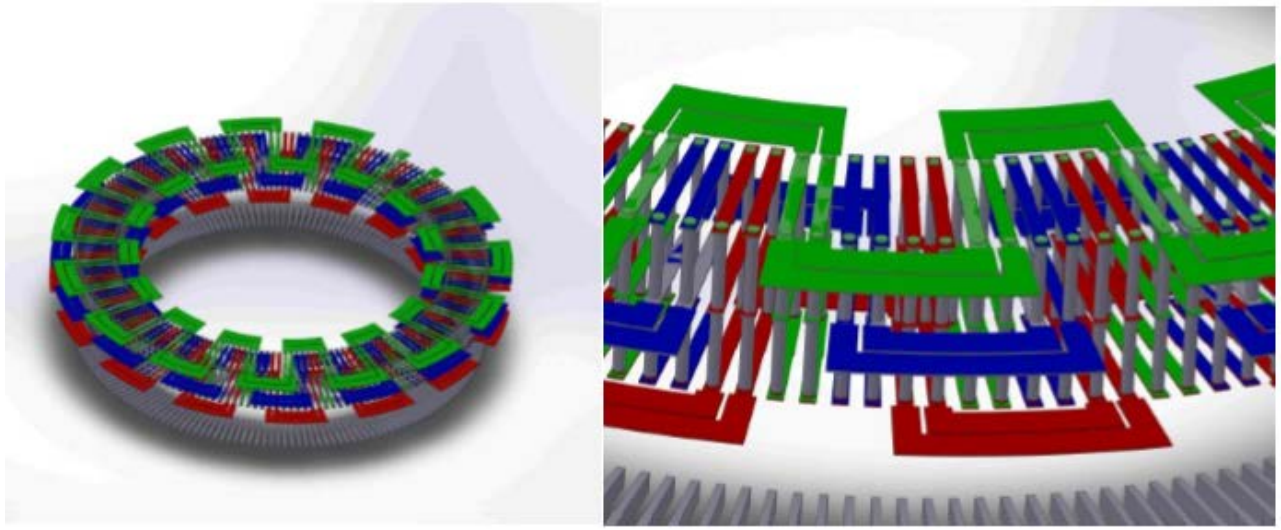
Rotors

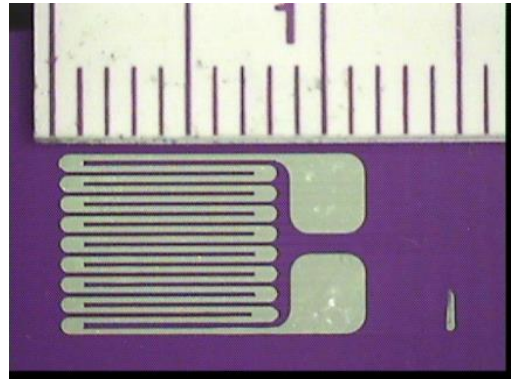
Additively Manufactured Rotor Plate

Rotor Constituents:

- Permanent magnets.
- High strength structure (typically metallic).

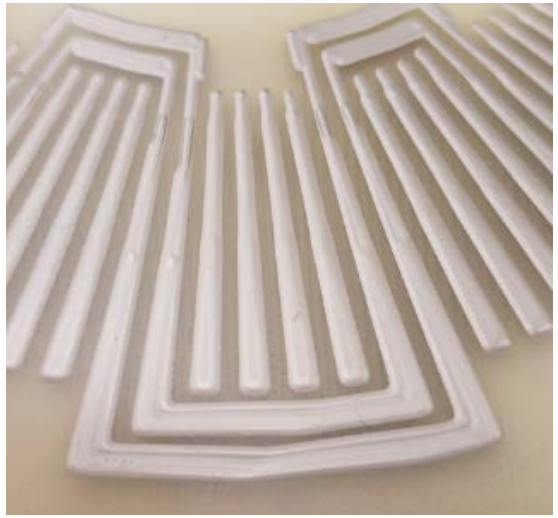
PCB Stator Concepts



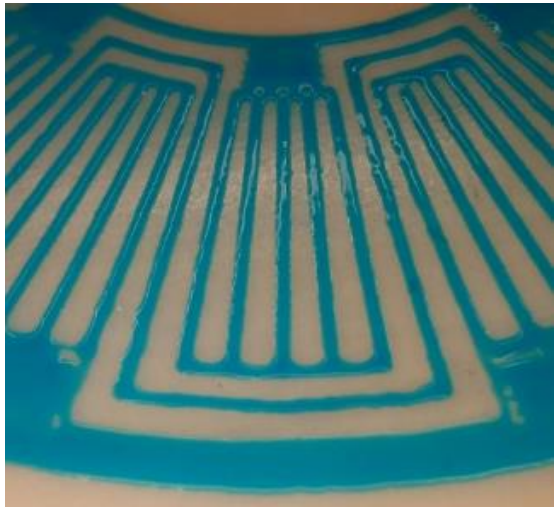


Printed strain gages.

Direct Printed Silver Conductor Layer



Direct Printed Dielectric Layer

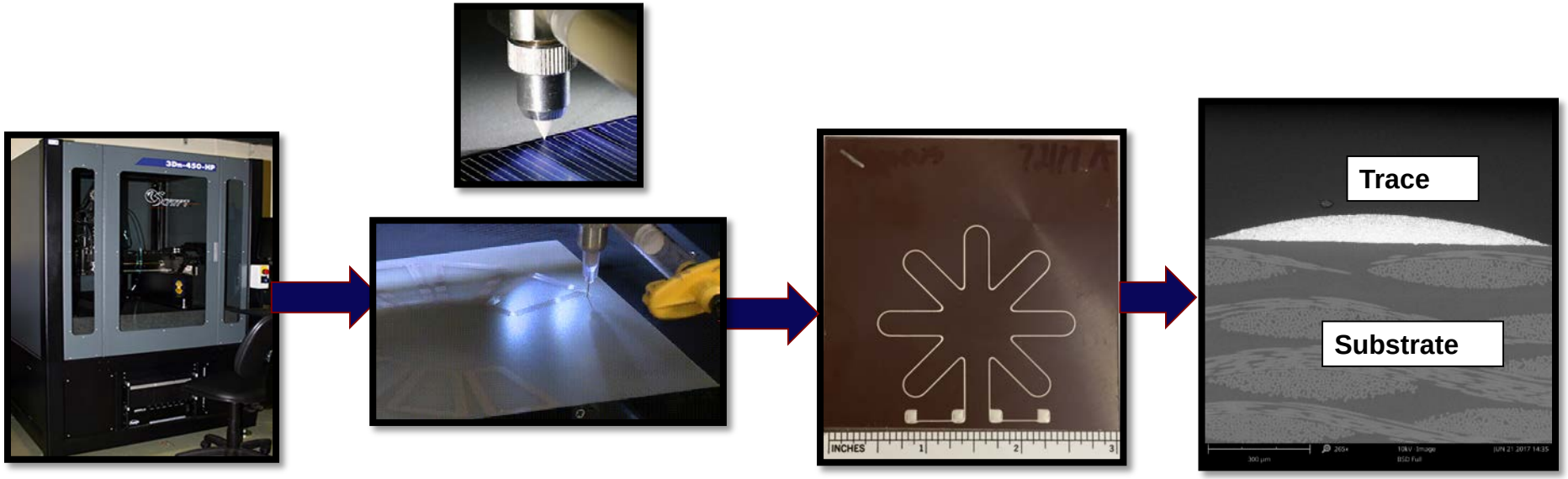


Direct Printing for Innovative Stator Designs for Electric Motors

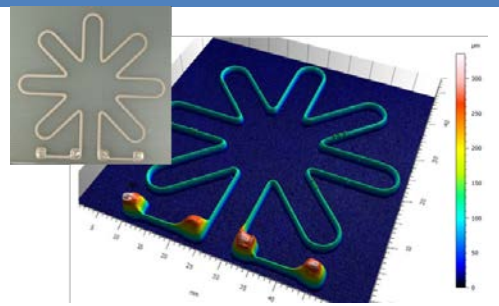
Samples were printed on the nScrypt 3Dn-300.

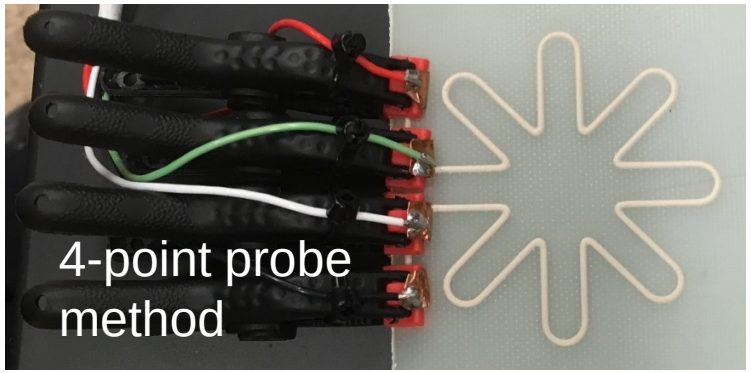
Crucial Parameters:

- Print Speed
- Dispensing Pressure
- Nozzle Diameter
- Print Offset
- Valve Opening

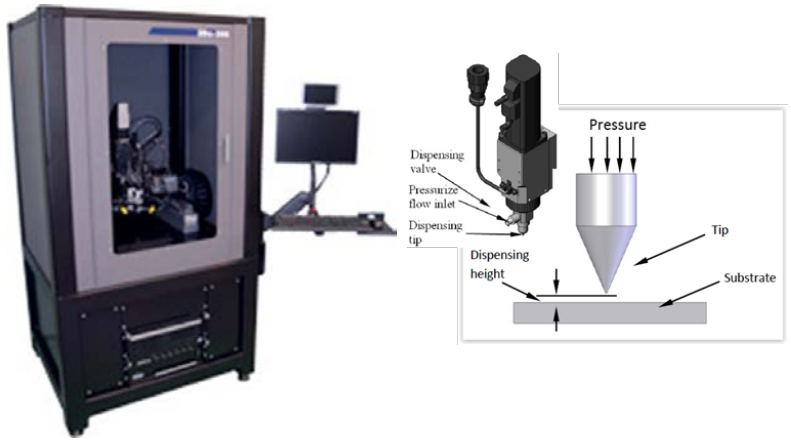


Thin Surface and Imbedded Thick 4-Pt Probe Windings

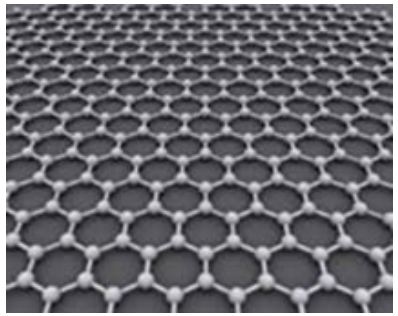


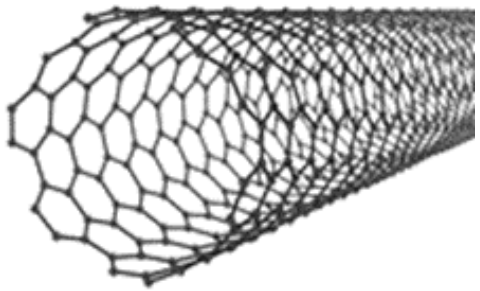


Advanced Higher Electrical Conductivity Silver System Through Carbon Nano-Structure Additions and Sintering Processes (GRC)



Carbon Nanostructure Additions





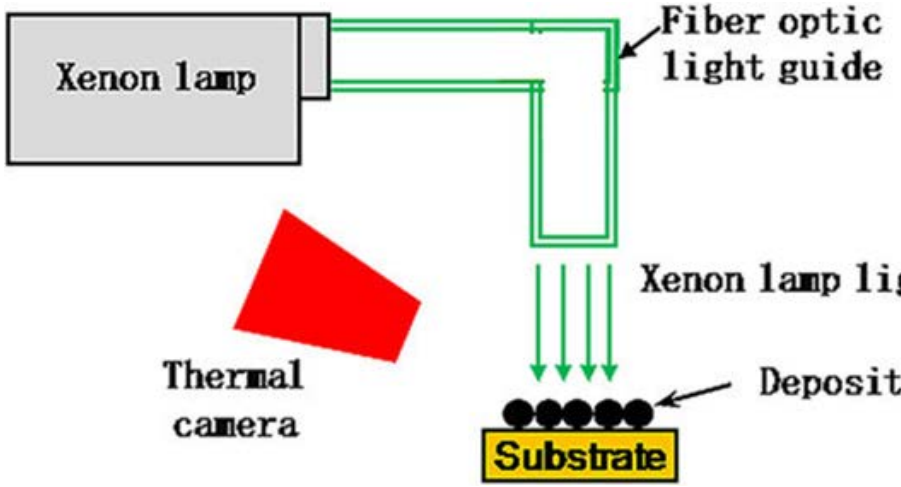
Graphene and Carbon Nanotubes

Much easier and faster iterations for investigating affects of additions to pastes compared to copper wire/stock (cold rolling and mixing issues).

Photonic Sintering

Investigating the use for photonic sintering for printed silver inks.

- Rapid post processing of conductive patterns
- Few second to minute processing times without damaging/heating the substrate



Sintering optimization by investigating offset distance, kV setting, pulses, duration, and nano-sized silver particle additions.

Summary

- NASA GRC has several additive manufacturing capabilities
  - Binder jetting for ceramics and metals
  - FDM of polymers for lightweight multifunctional applications
  - Direct printing of conductors and sensors
- The AM capabilities and experience can be leveraged for partnerships in other areas.