Printing Multi-Functionality with Multi-Technology Additive Manufacturing

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W.M. KECK CENTER
FOR 3D INNOVATION

Where is UTEP?

Keck Center in the Beginning (August 2000)

Keck Center: Key Initial Partnerships/Investments

W.M. KECK CENTER
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Universities - National and International

LELAND STANFORD JUNIOR UNIVERSITY
DIE LUFT DER FREIHEIT WEHT
1891

UTEP

W.M. KECK FOUNDATION

Government Agencies, Private Foundations and National Laboratories

Sandia National Laboratories

W.M. KECK CENTER
FOR 3D INNOVATION

SIERRA PROVIDENCE
HEALTH NETWORK

Arango Imaging Center

Dr. Edward Egbert, M.D.

Individual Supporters, Physicians and Surgeons

STRATASYS®
Make It Real™

DSM Somos®

Industry

Keck Center: Continuously Expanding Productive Partnerships

Universities - National and International

Government Agencies, Private Foundations and National Laboratories

Dr. Edward Egbert, M.D.

Individual Supporters, Physicians and Surgeons

Industry

W.M. Keck Center for 3D Innovation

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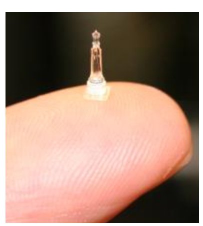
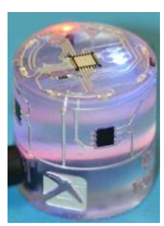
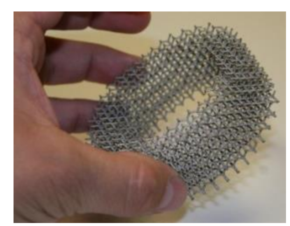
- 13,000 sq. ft. (~1200 sq. m.), state-of-the-art facility
- More than 40 Additive Manufacturing (AM) machines (polymers, metals, ceramics, composites, electronics, biomedical)
- More than 50 currently involved faculty and students
- 6 full-time staff
- ITAR compliant, UTEP SCIF in late 2013
- Everything we do uses additive manufacturing technologies






Facilities

Facilities

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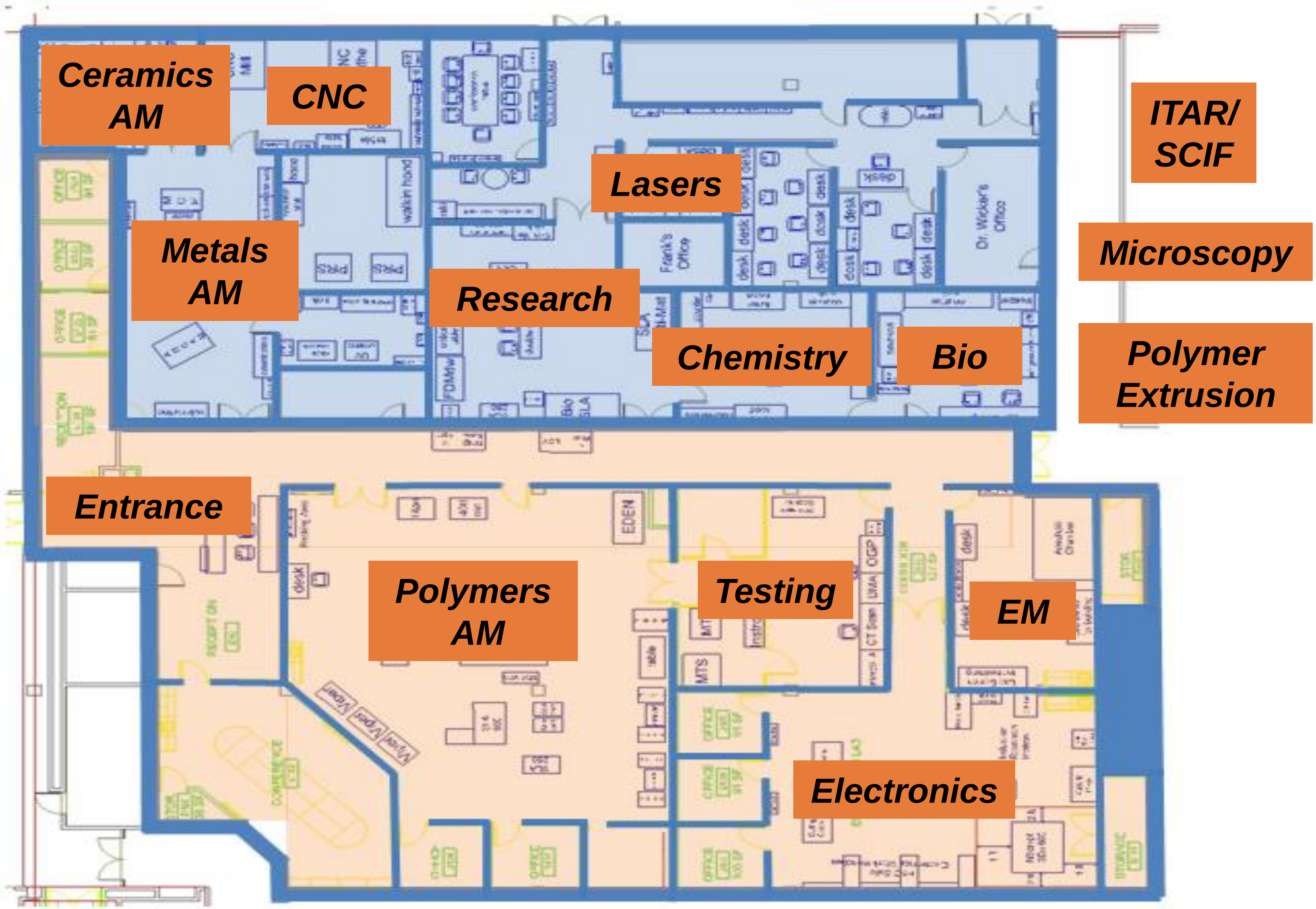
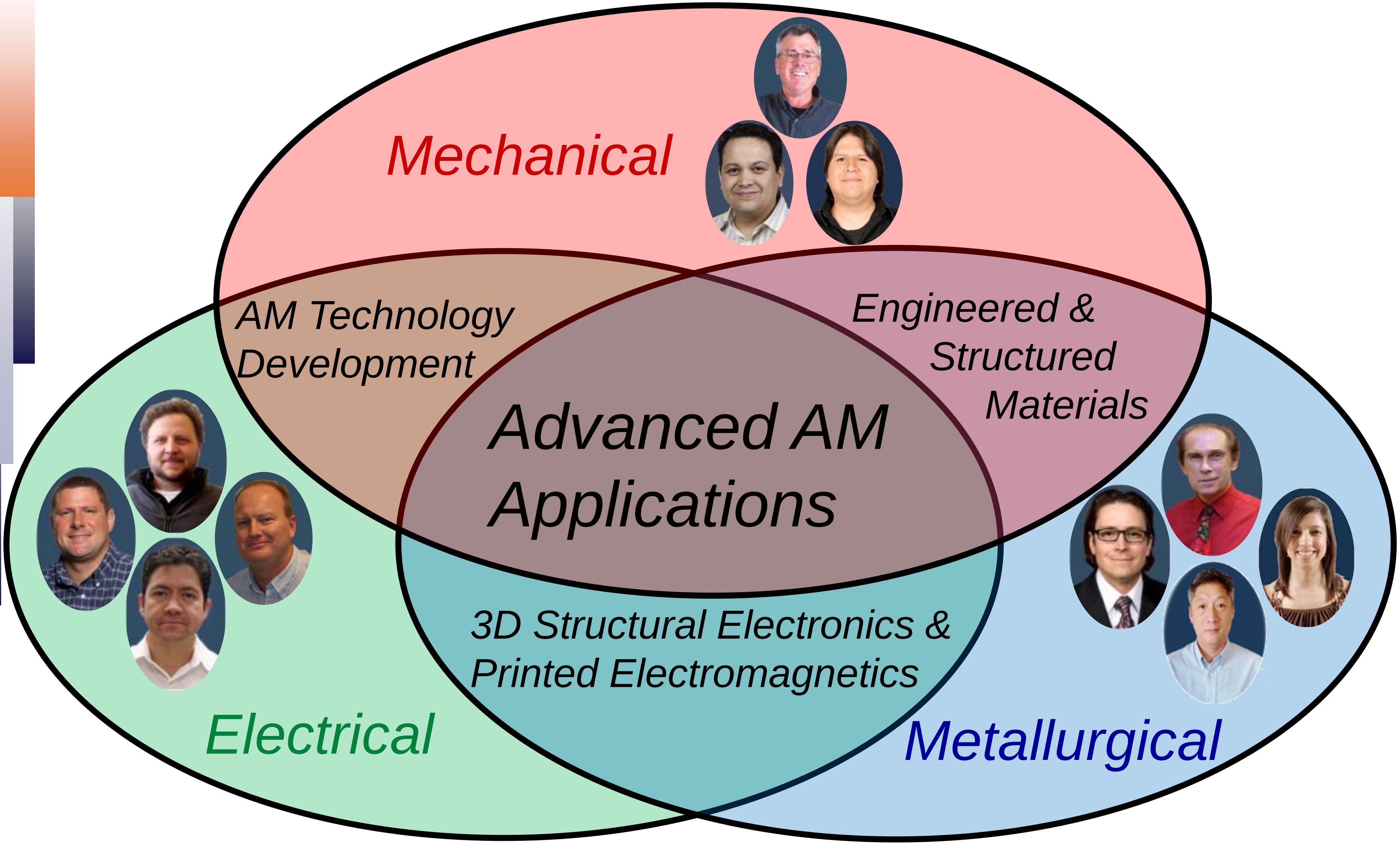


Center Focus and Expertise

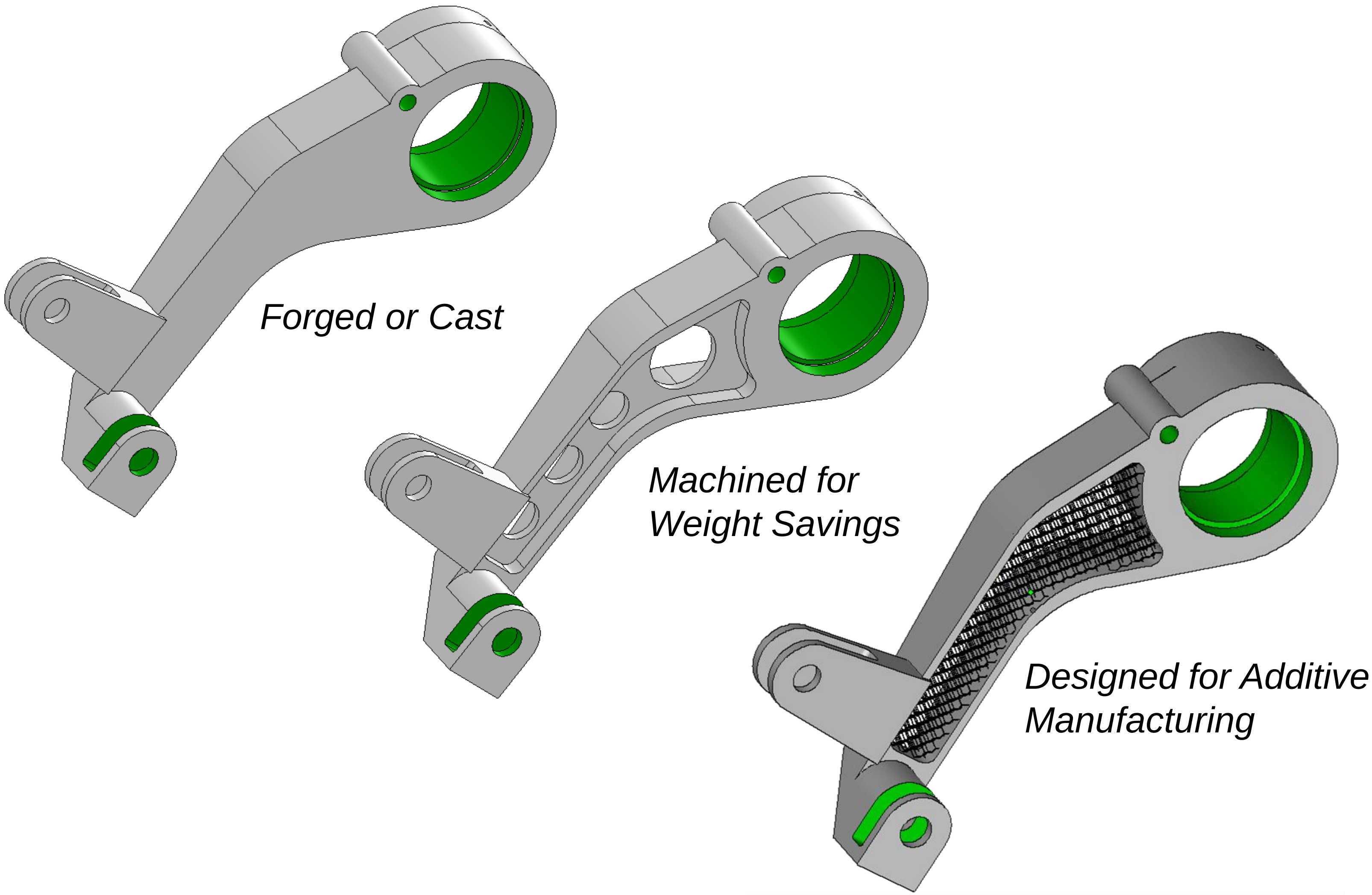


ASTM F42 Standards Committee Process Categories

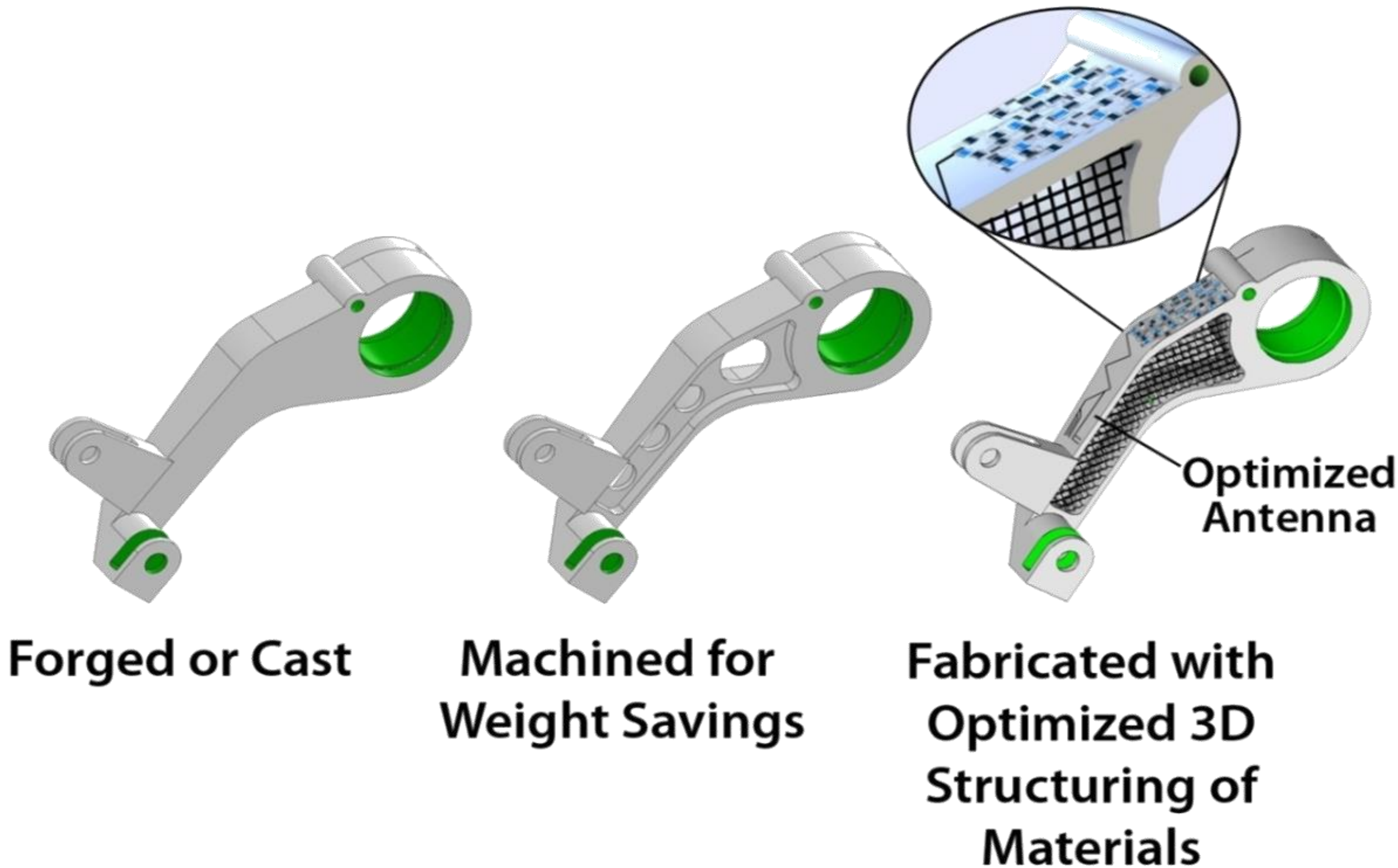
- Vat Photopolymerization
- Material Extrusion
- Powder Bed Fusion
- Material Jetting
- Binder Jetting
- Sheet Lamination
- Directed Energy Deposition

AM Technologies Available within the UTEP Keck Center

Design for Additive Manufacturing



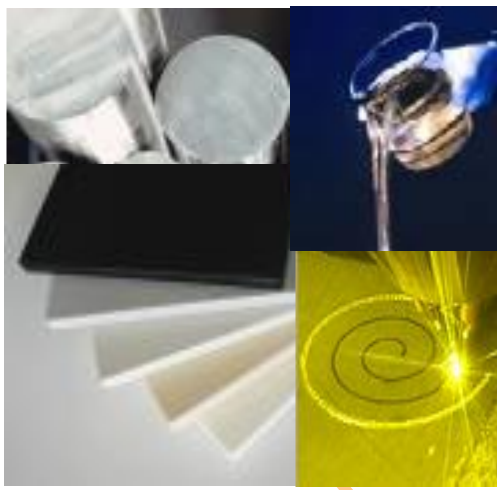
AM Advantage: Multi-functionality



Multi-Material, Multi-Technology AM

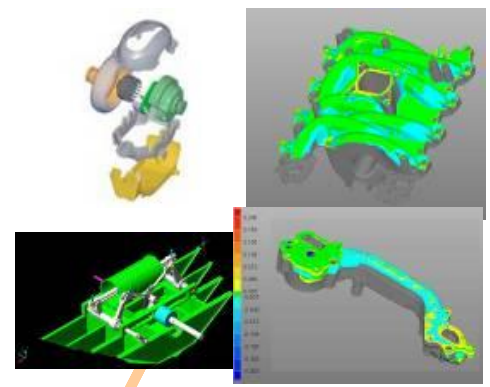
Rapid manufacturing of functional devices using integrated technologies

Materials

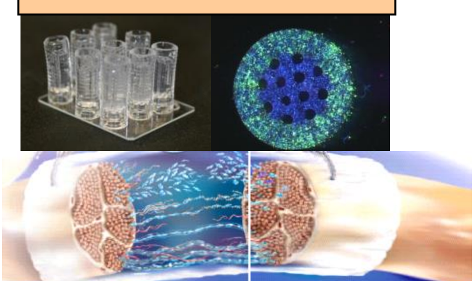


Additive / Subtractive Manufacturing Technologies

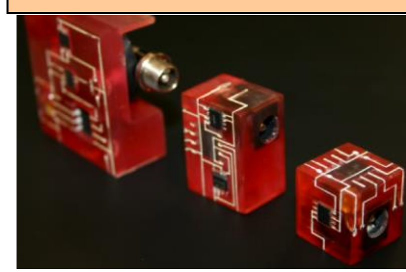
Software



Tissue Engineered Bioactive Scaffolds



3D Structural Electronic Devices



Fully Functional Devices

Enabling Technologies: Multi-Material SL Machine

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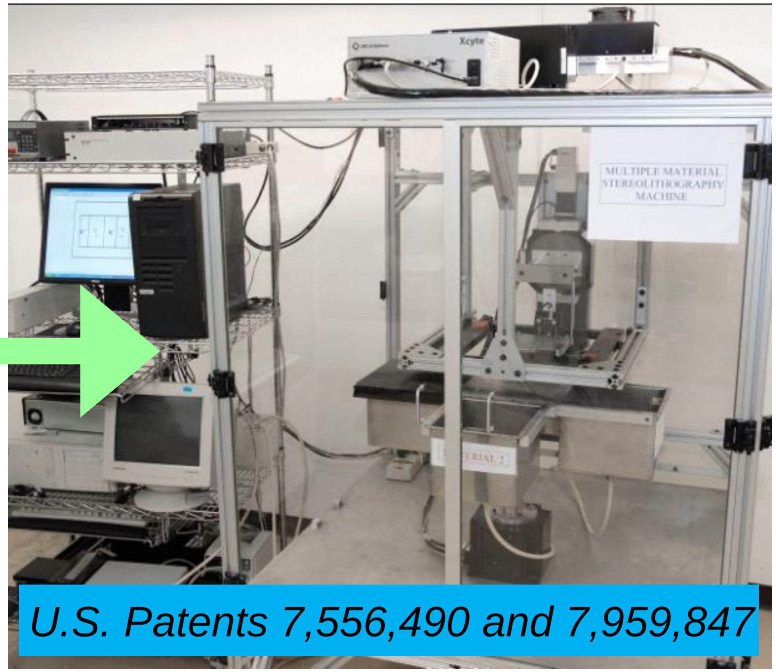
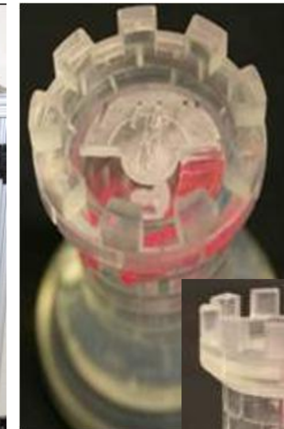
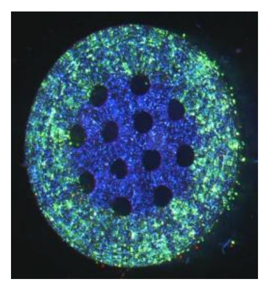
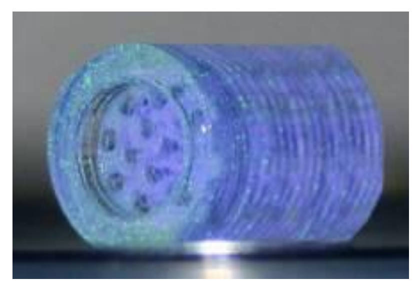


U.S. Patents 7,556,490 and 7,959,847







Wicker, MacDonald, "Multi-Material, Multi-Technology Stereolithography," Virtual and Physical Prototyping, 2012.
Choi, Kim, Wicker, "Multi-Material Stereolithography," J. of Materials Processing Technology, 2011.

Bio-fabrication

CBET-0730750

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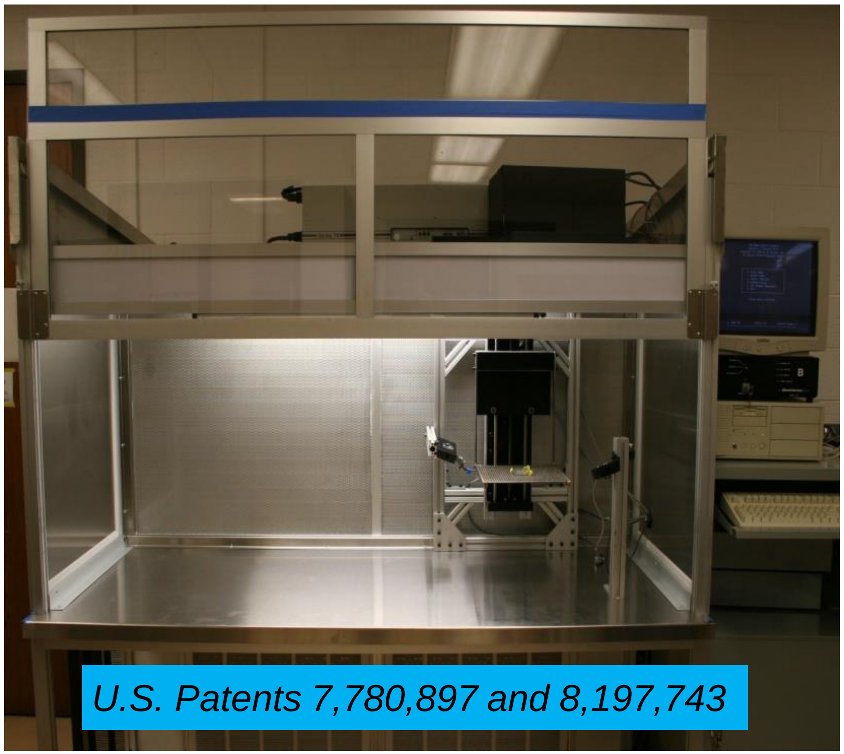
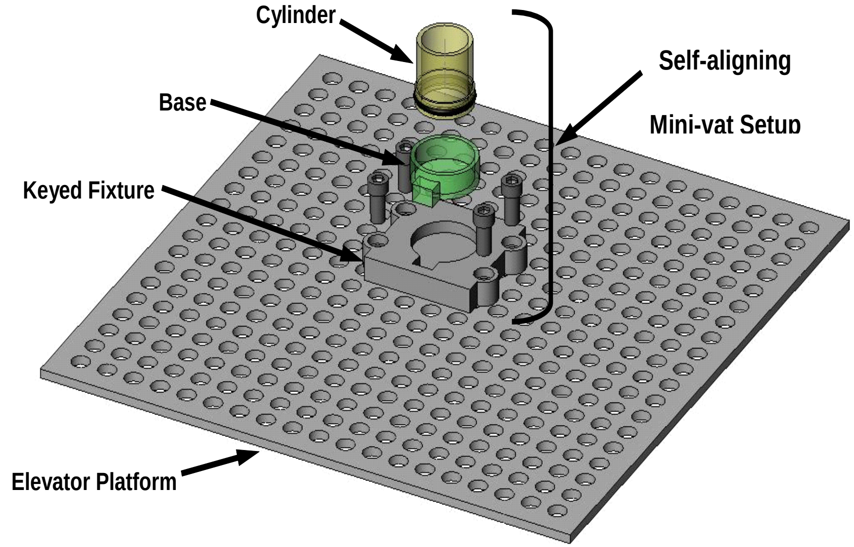
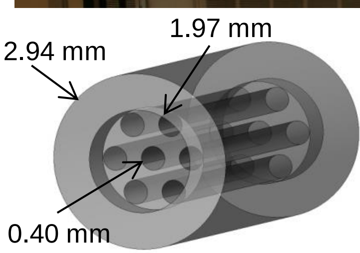
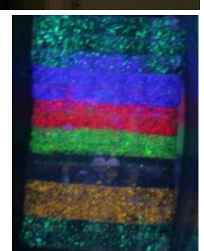
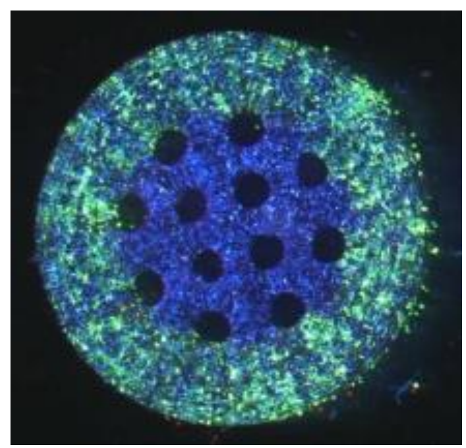


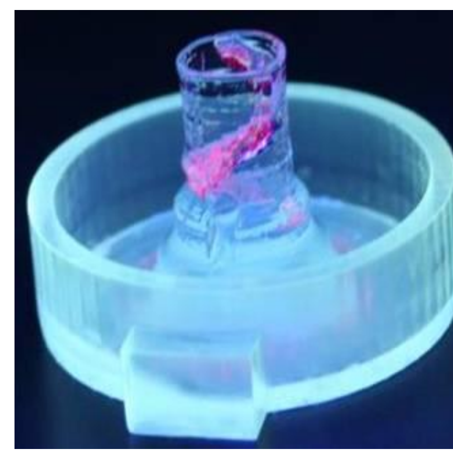
U.S. Patents 7,780,897 and 8,197,743





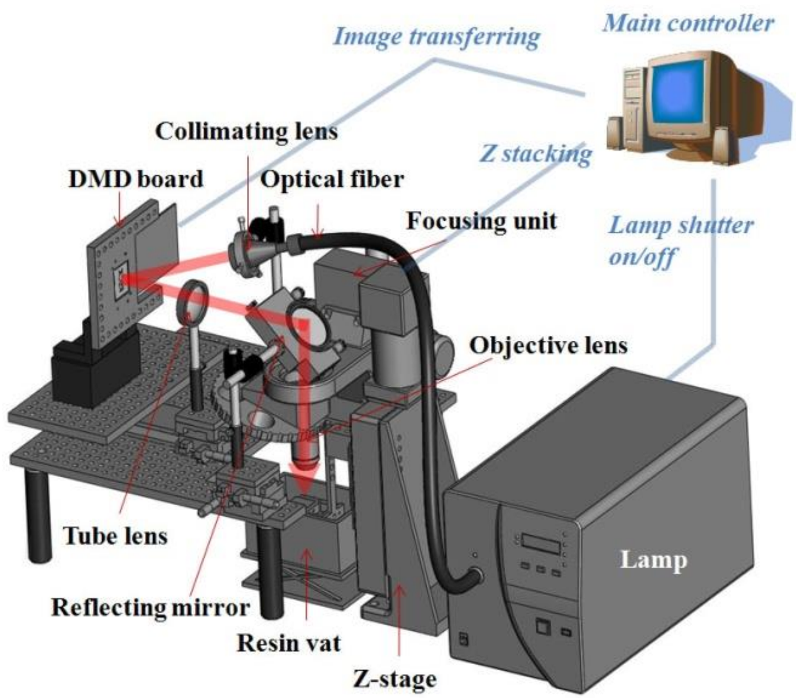


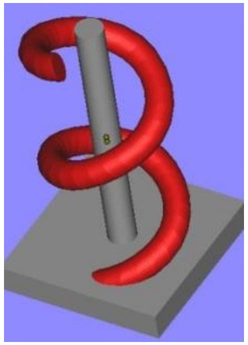


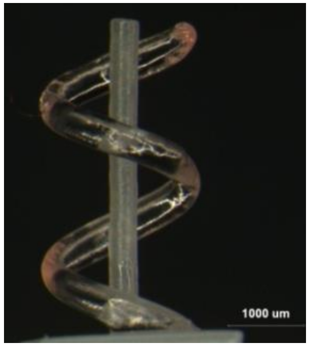


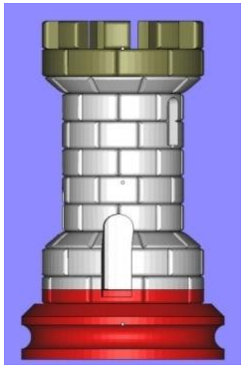
Arcaute, Mann, Wicker, "Stereolithography of Spatially-Controlled Multi-Material Bioactive Poly(ethylene glycol) Scaffolds," Acta Biomaterialia, 2010.

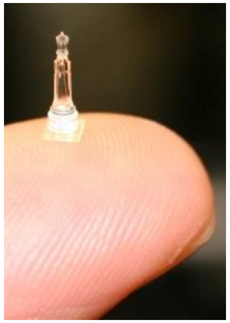
Micro-SL System with Multi-Material Capabilities

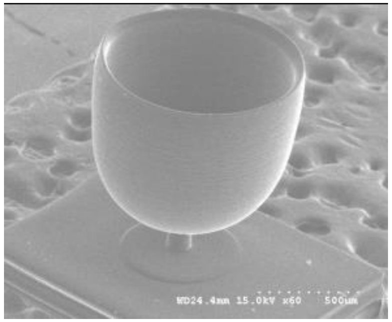


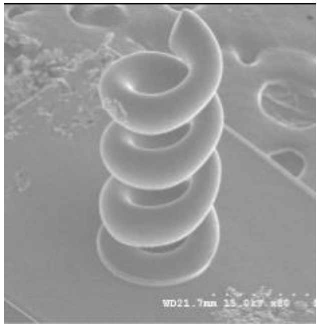


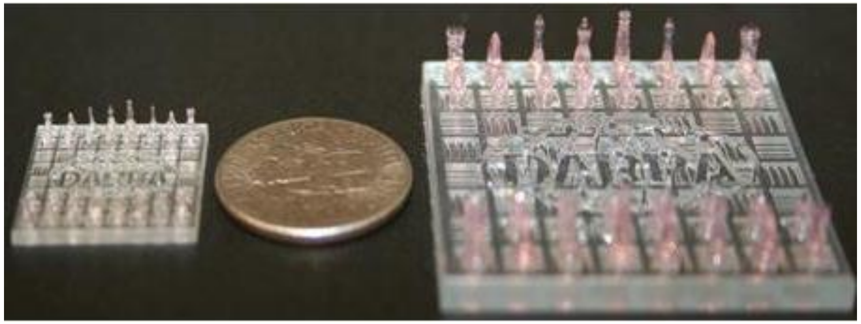












Choi, MacDonald, Wicker, "Multi-Material Microstereolithography," IJAMT, 2010.

Multi-Technology: SL Integrated with Direct-Print

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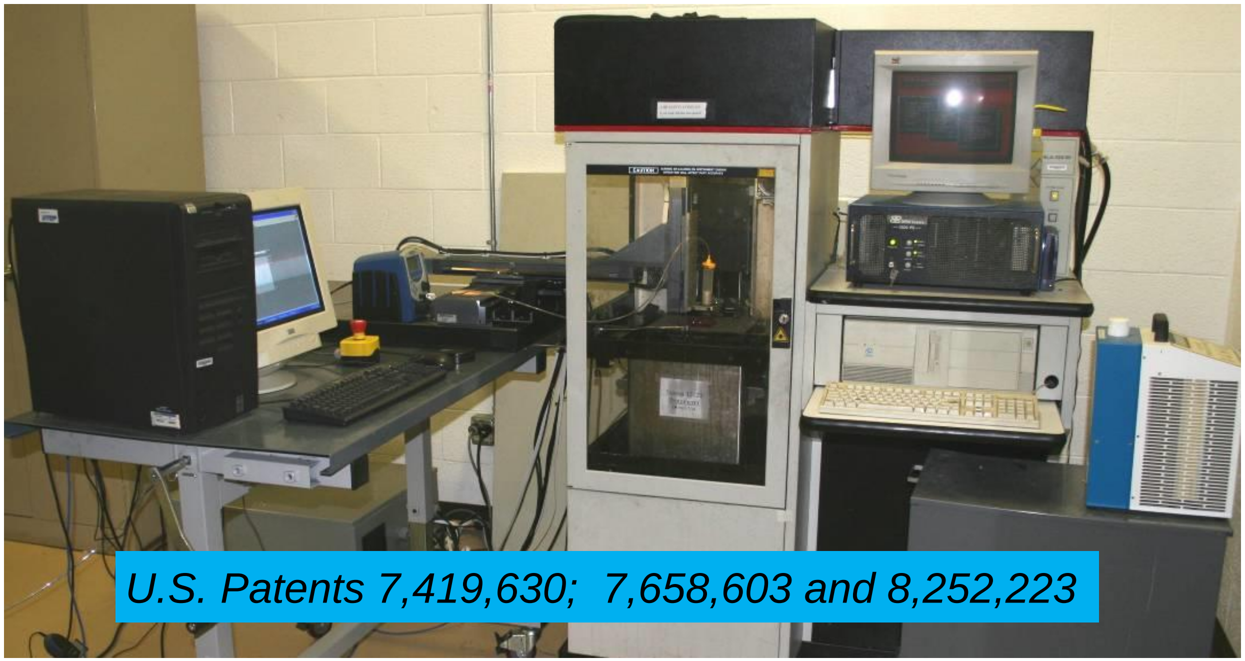
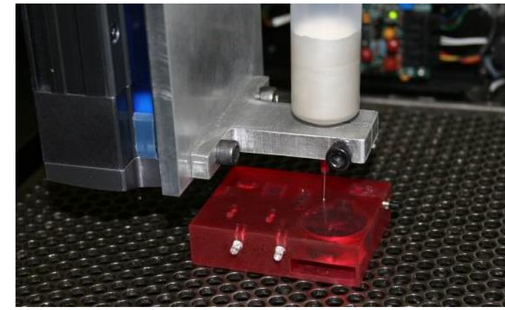
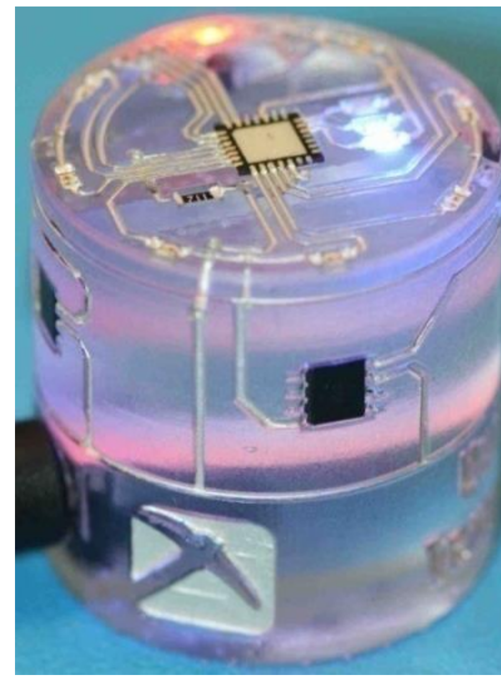
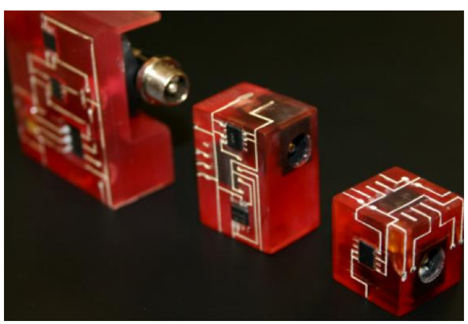
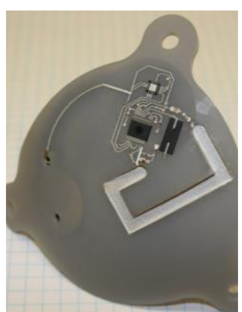


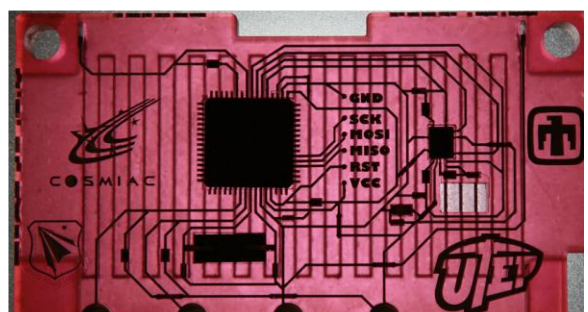
U.S. Patents 7,419,630; 7,658,603 and 8,252,223











Lopes, MacDonald, Wicker, "Integrating Stereolithography and Direct Print Technologies for 3D Structural Electronics Fabrication," Rapid Prototyping J., 2012.

Advantages of 3D Structural Electronics

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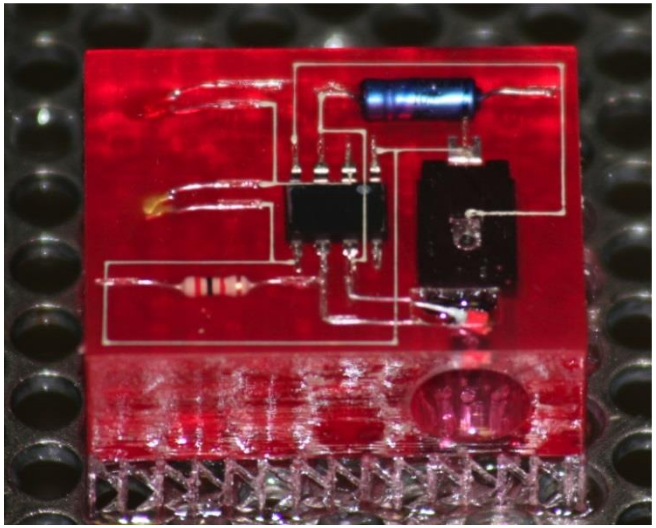
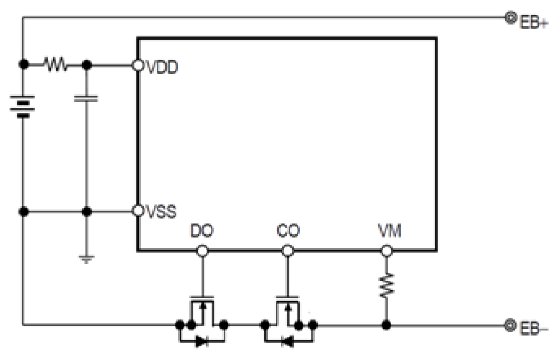
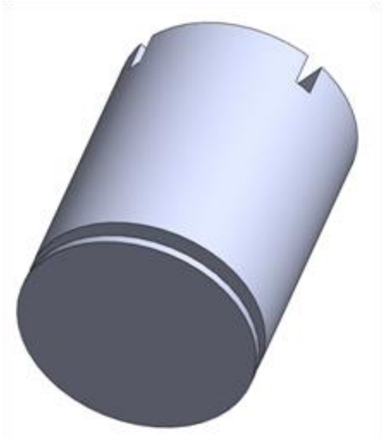
- *Intricately-Detailed Unit-Level Customized 3D Form*
  - *Potential to accommodate and incorporate micro-systems*
  - *Embedded in structural components*
  - *Conformal (human anatomy specific)*
- *Multiple materials*
  - *Bio-compatible*
  - *Strong, lightweight*
  - *Flexible substrates*
- *Tight 3D Integration*
- *Integrated Thermal Management*
- *Reverse Engineering / Tamper Resistant*
- *Rugged and Potential for Remote Fabrication*



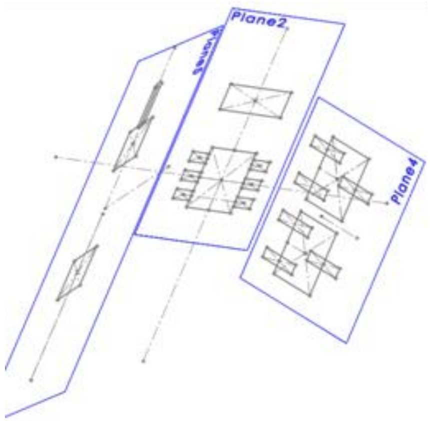
Methodology: CAD Challenges in 3D



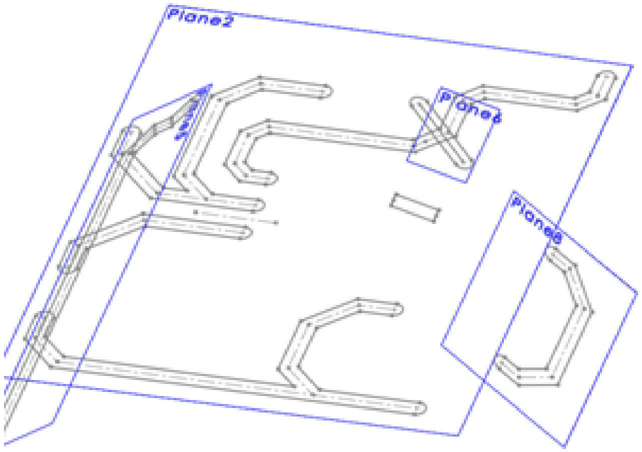
EE CAD - Schematic Design



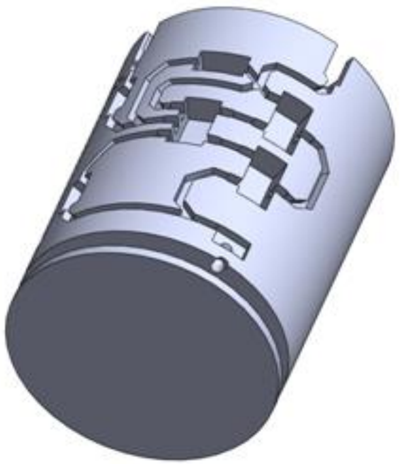
ME CAD - Shape and Constraints



ME CAD - Components Cavities



EE to ME CAD - Interconnects



ME CAD - Finalize Design

3D Structural Electronics Demonstration: Gaming Die

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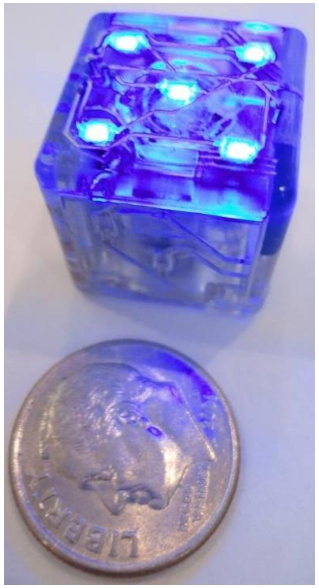
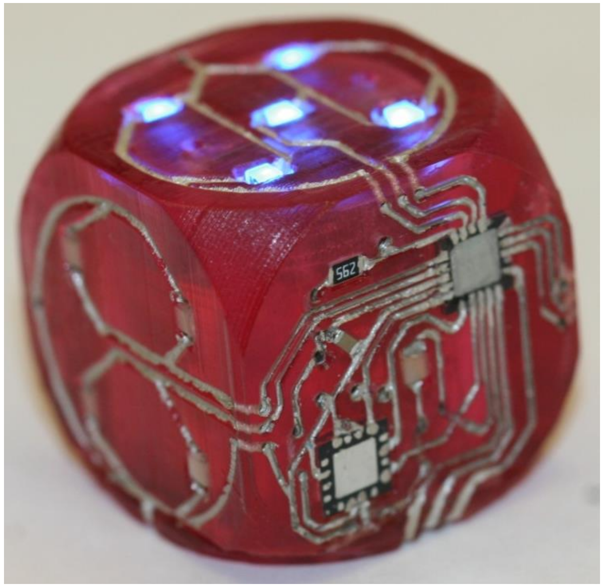
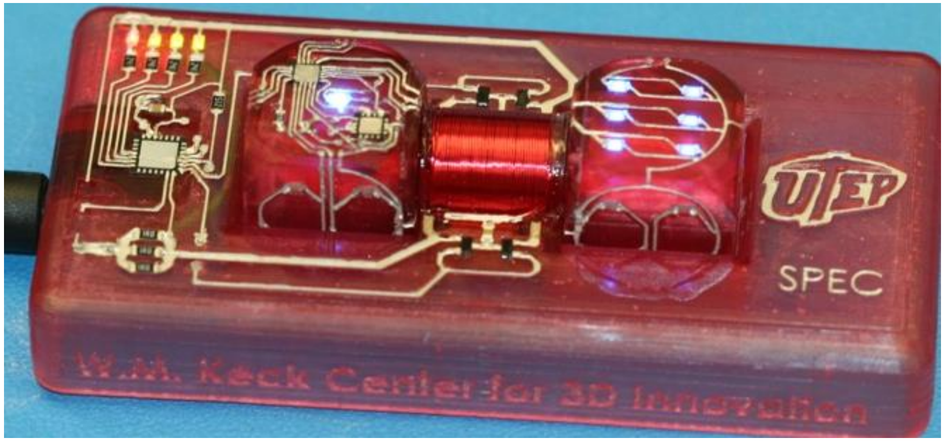
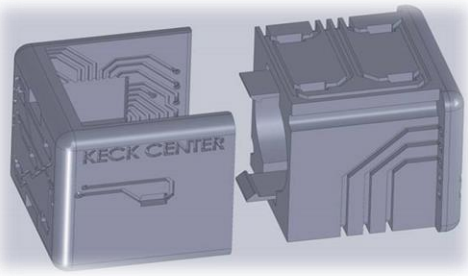






- Microprocessor and accelerometer identify top surface and display LEDs
- Electronics on all six sides with two-piece assembly design
- Advanced induction wireless charging
- Challenges:
  - CAD (mechanical structures, electronics, integration in 3D)
  - Ink electrical performance
  - Overall reliability



Possible Application: Rapid Design and Deployment of Satellites

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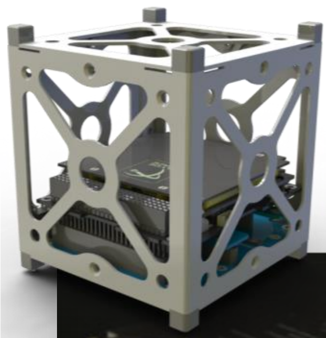
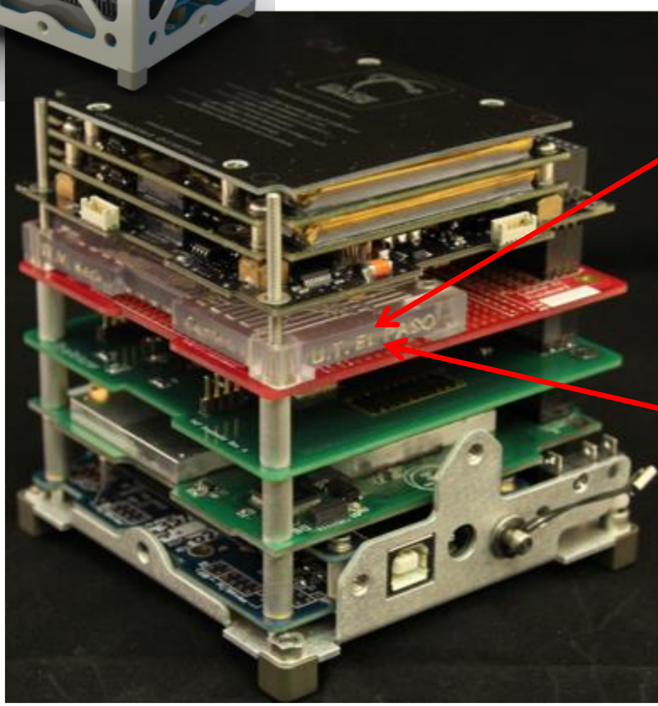
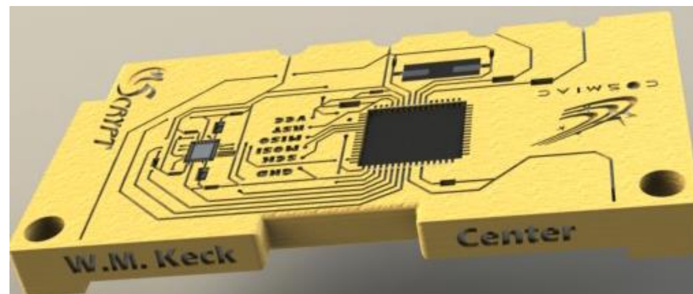
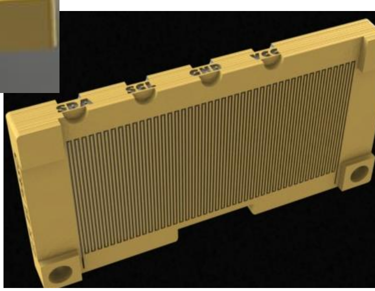
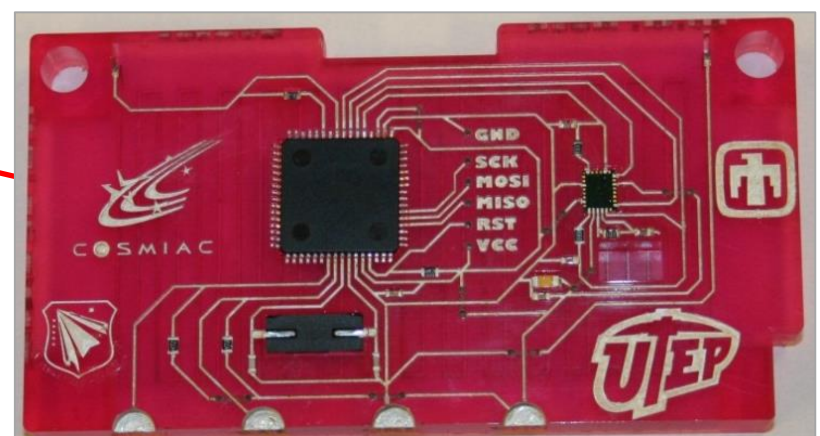
- *Developing ASIM sensor system to provide volumetric efficiency for CubeSat launch (Trailblazer) in August 2013*





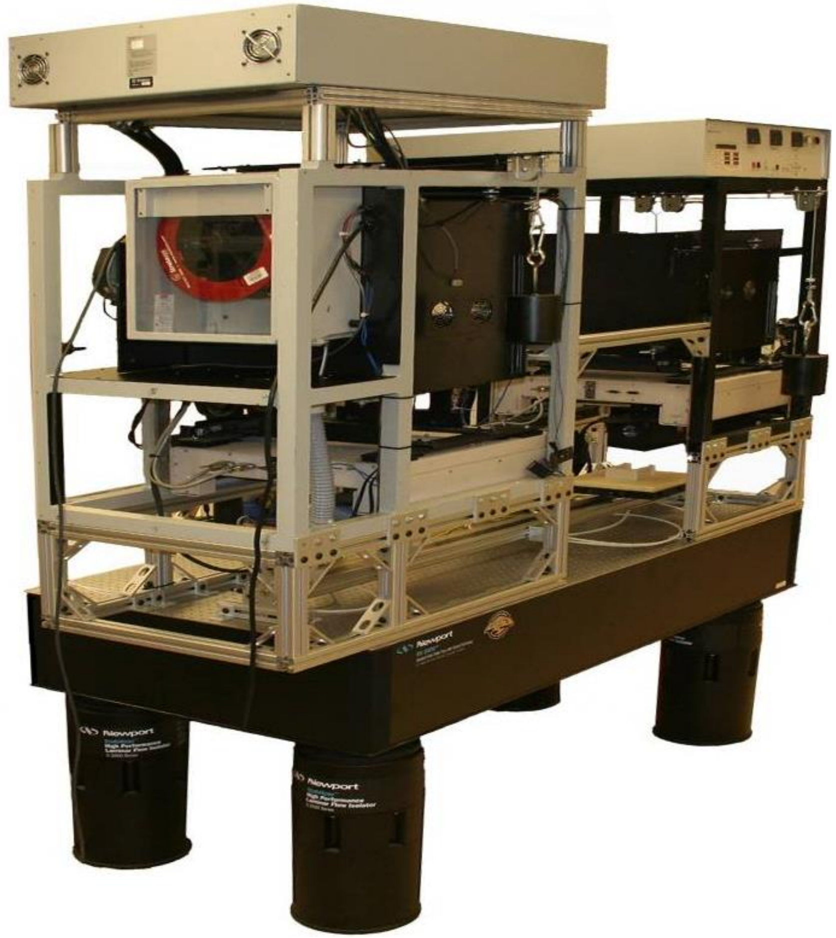




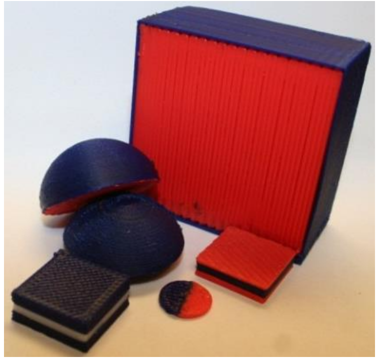


How about other AM technologies?

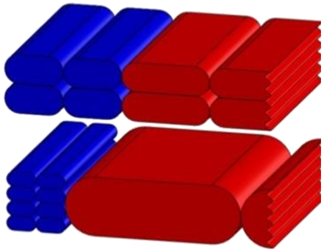
Multi-Material, Multi-Technology FDM

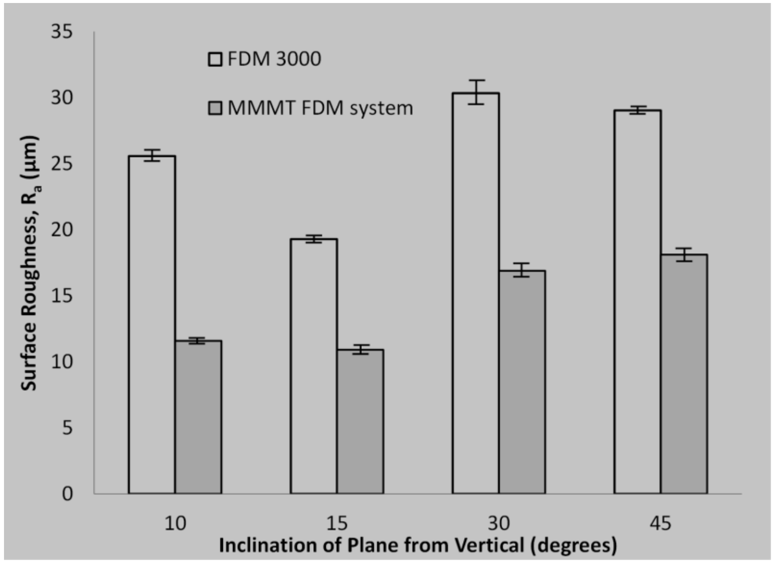


Multiple Materials



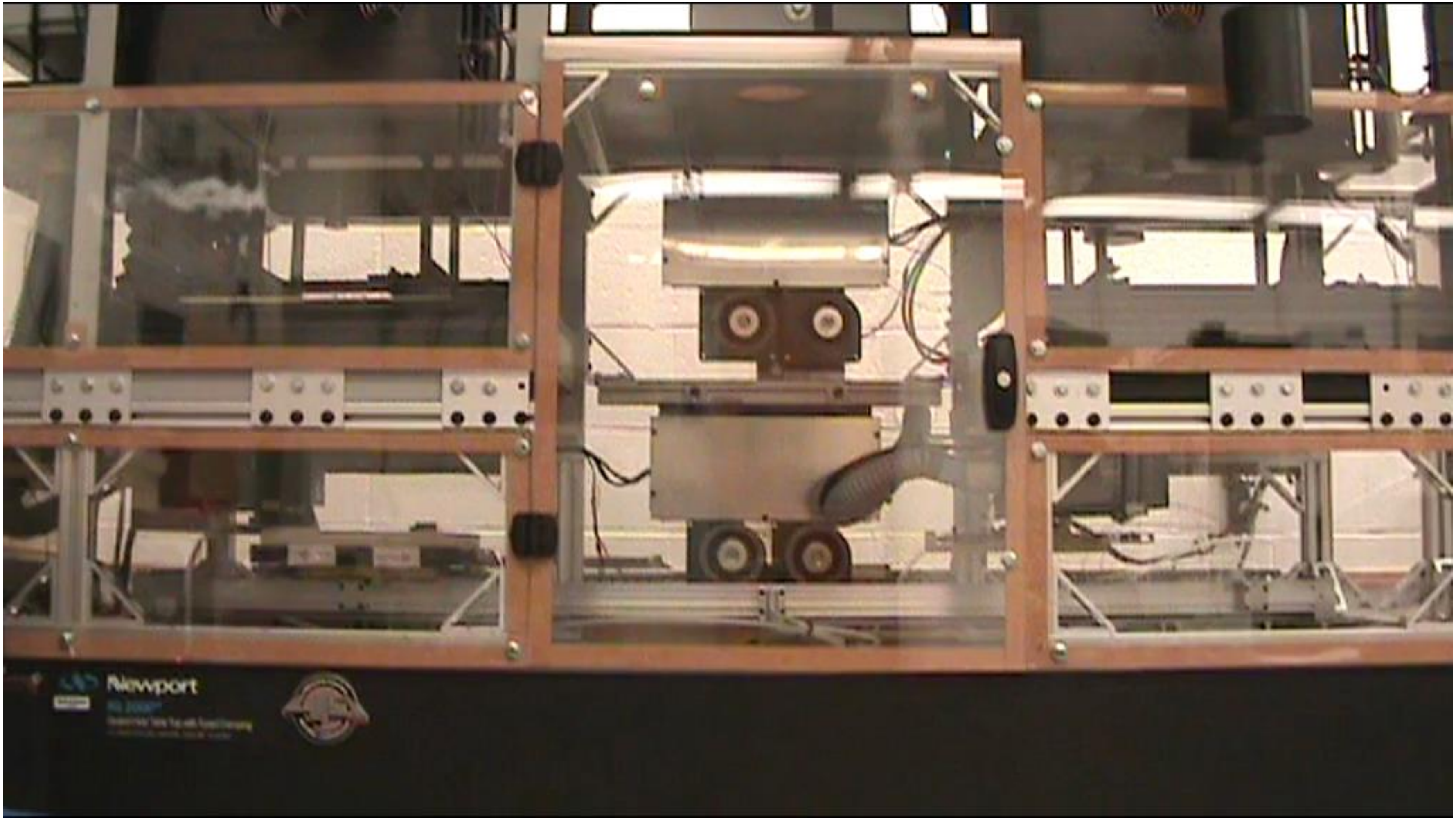
Variable Build Strategies





Choi, Medina, Kim, Espalin, Rodriguez, Stucker, Wicker, "Development of a Mobile Fused Deposition Modeling System with Enhanced Manufacturing Flexibility," J. of Materials Processing Technology, 2011.

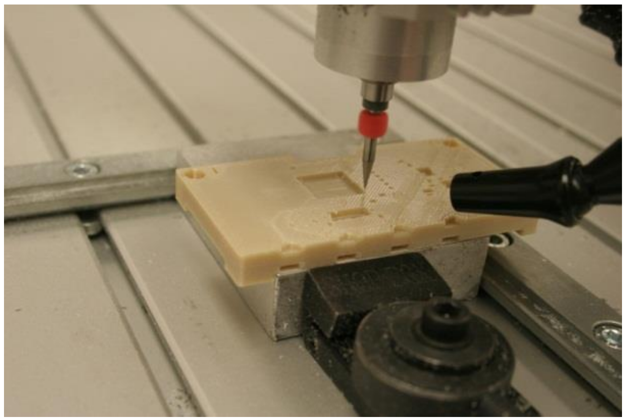
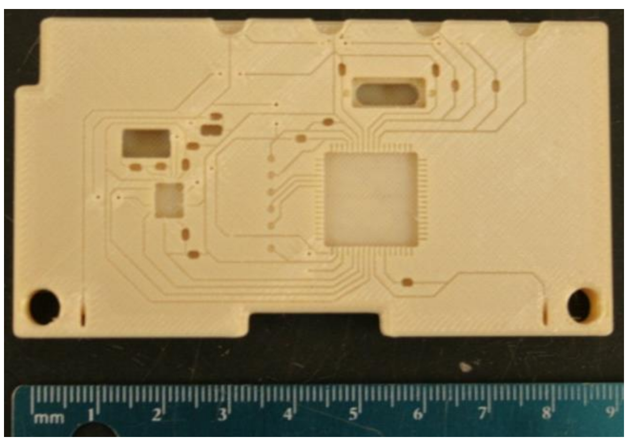
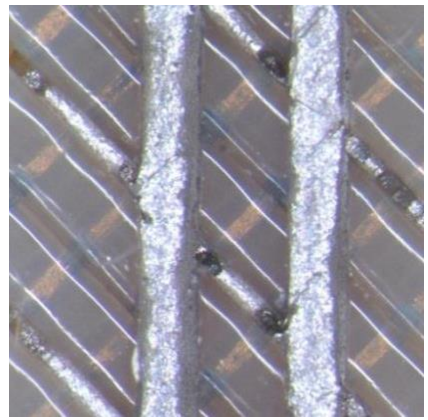
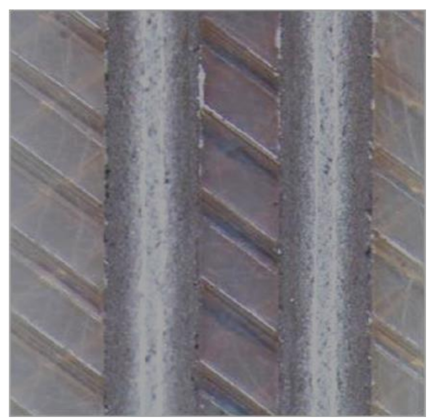
Multi-Material, Multi-Technology FDM



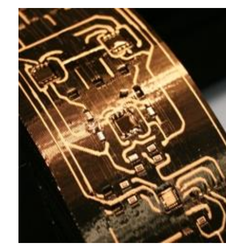
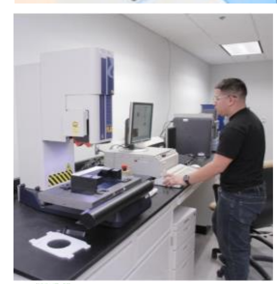
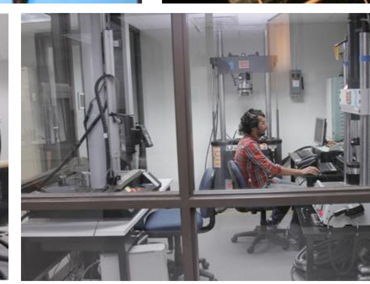
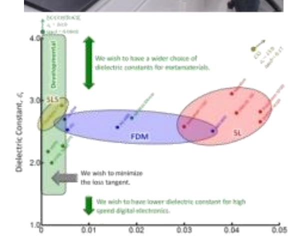
Espalin, Ramirez, Medina, Wicker, "Multi-Material, Multi-Technology FDM: Exploring Build Process Variations," Rapid Prototyping J., to appear, 2013.

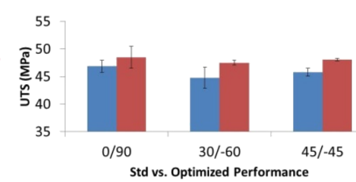
FDM and 3D Structural Electronics

Microelectronics – resolution requirements	Conductive inks – dispensing and curing	Final Performance





Advancements in FDM

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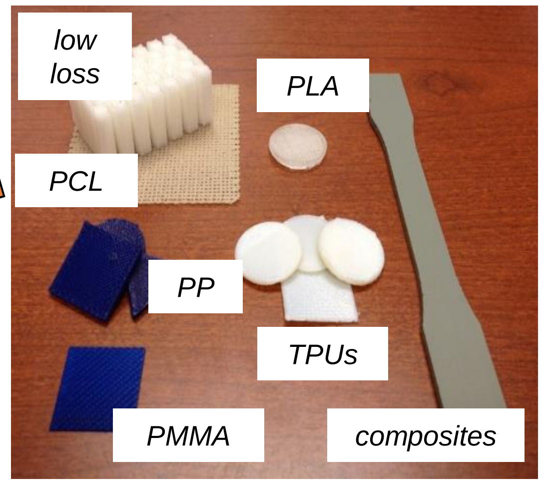
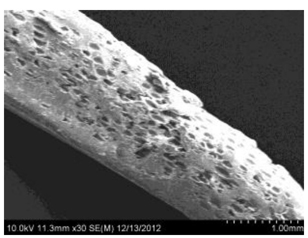
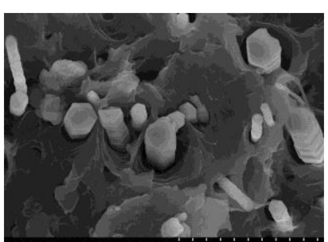
FDM Filament Development

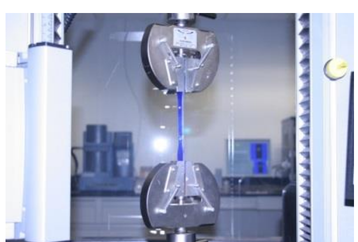
FDM Process Parameter Development



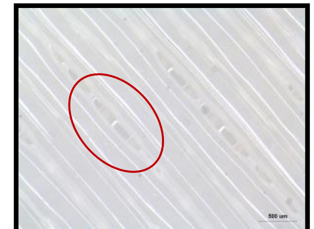
Materials Characterization



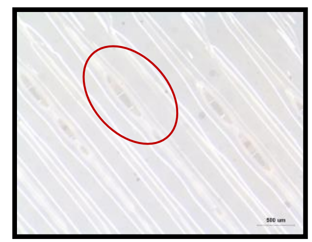




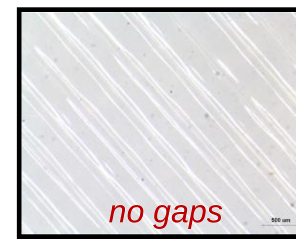
FDM Processing Optimization



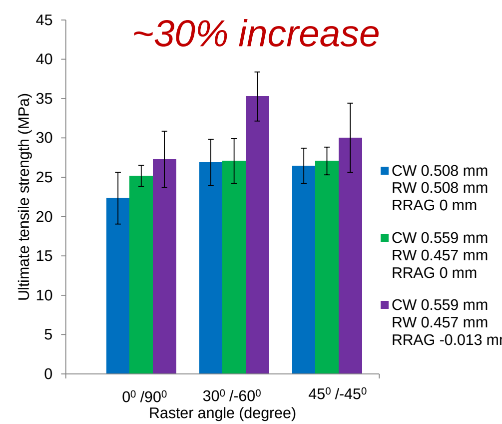
Standard/Default



Insight Revision



Optimized



FDM and Electronics

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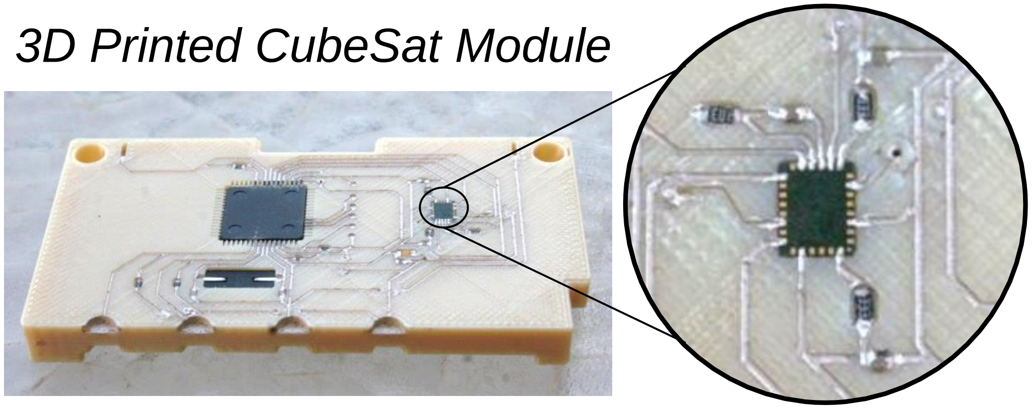
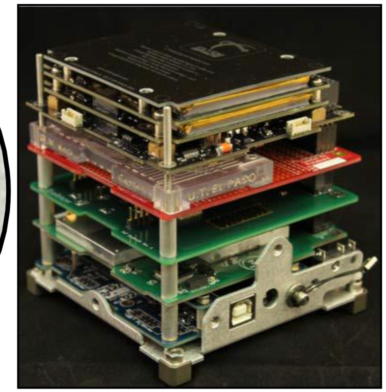
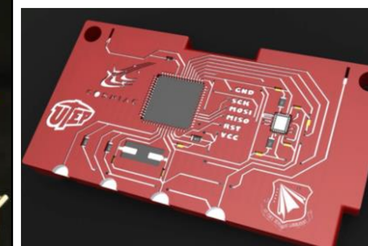
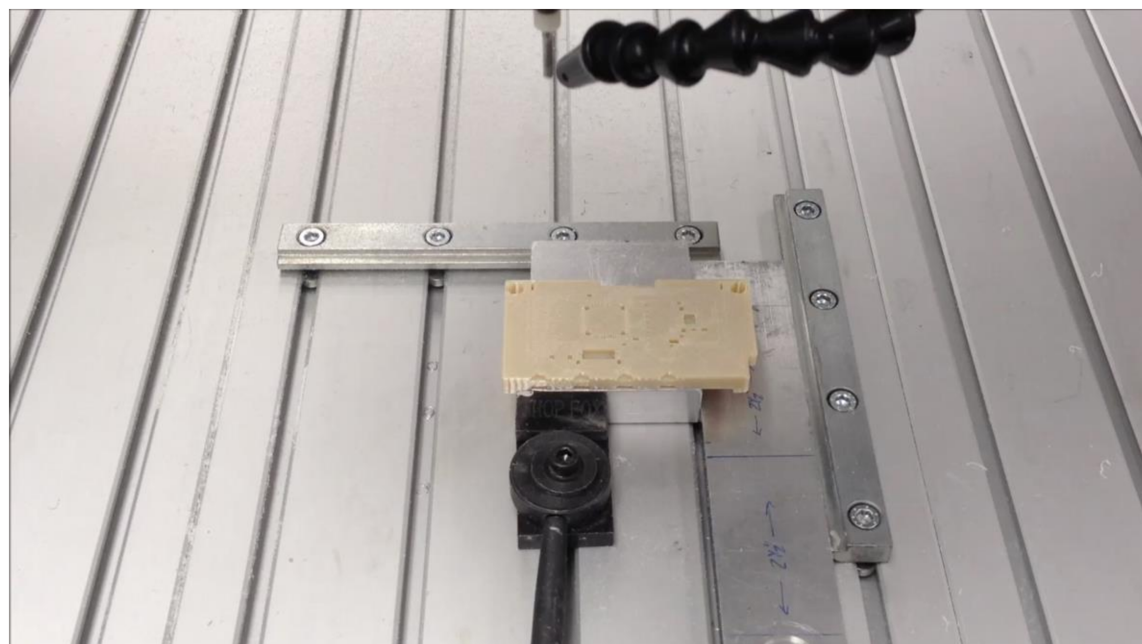
3D Printed CubeSat Module



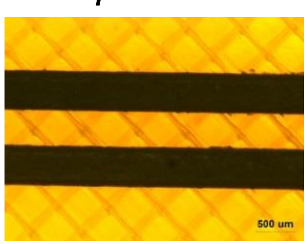






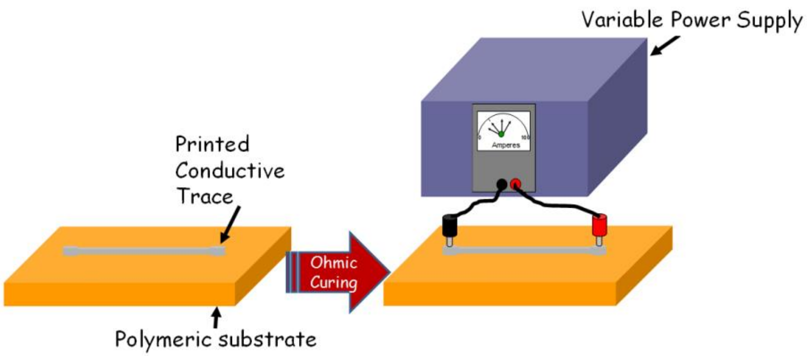
Standard

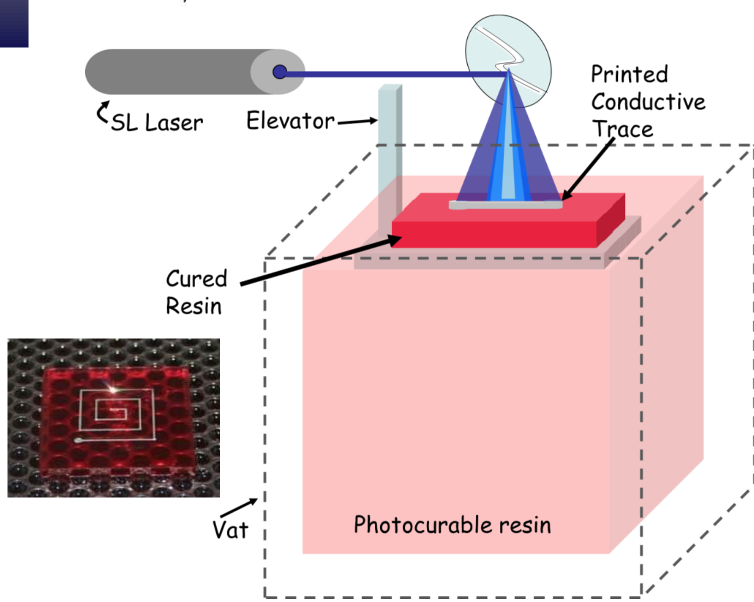
Optimized



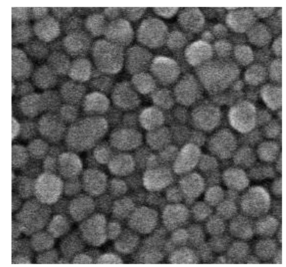
Ink Curing and Performance

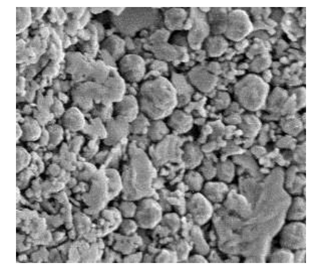
Different In Situ Curing Strategies

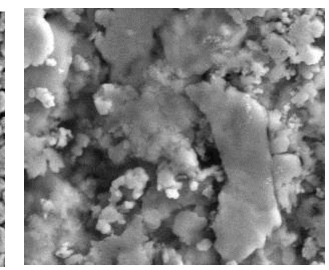




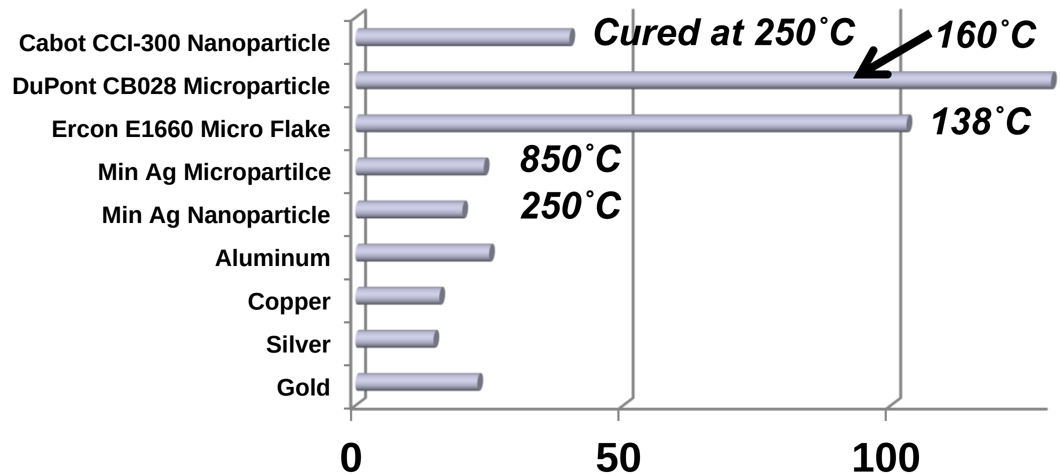
Different Ink Morphologies


Nano


Micro


Flake

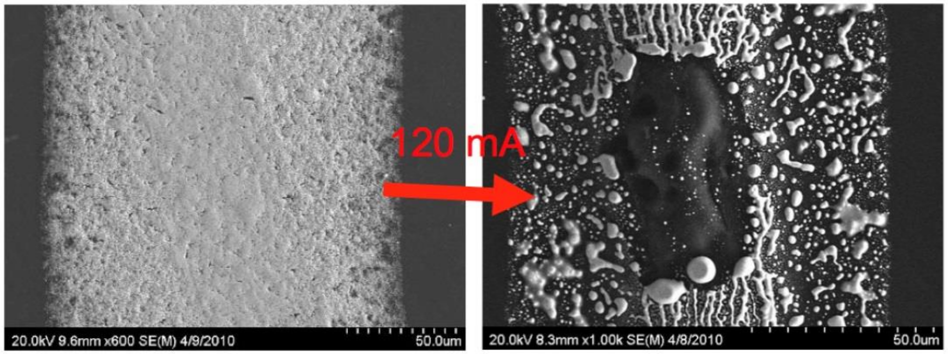
Resistivity nΩ·m



Roberson, Wicker, MacDonald, "Ohmic Curing of Printed Silver Conductive Traces," J. of Elect. Mtls., 2012.

Are conductive inks adequate?

- *Low conductivity = low current carrying capacity*
- *High resistance is undesirable*
  - *Self heating*
  - *Voltage drop*
  - *Reduced reliability*
  - *Reduced performance*



The standard

Case	Geometry	Resistance (ohms)
one-ounce copper PCB with 4 mil width	37 µ thick, 100 µ wide, conductor 10 cm long	0.45
Dupont Ink CB028 Silver	25 µ thick, 100 µ wide, conductor 10 cm long	4.73
Dupont Ink CB500 Copper	25 µ thick, 100 µ wide, conductor 10 cm long	20.27
Extruded Solder	25 µ thick, 100 µ wide, conductor 10 cm long	2.86
40 gauge wire 10 cm long	80 µ diameter, conductor 10 cm long	0.33
36 gauge wire 10 cm long	120 µ diameter, conductor 10 cm long	0.15
32 gauge wire 10 cm long	200 µ diameter, conductor 10 cm long	0.05

Solder FDM

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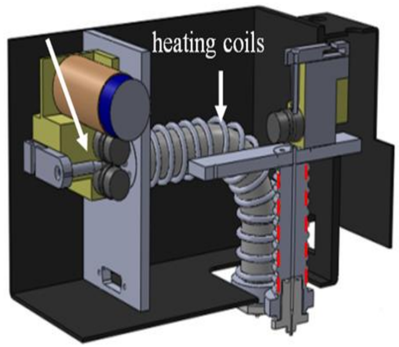
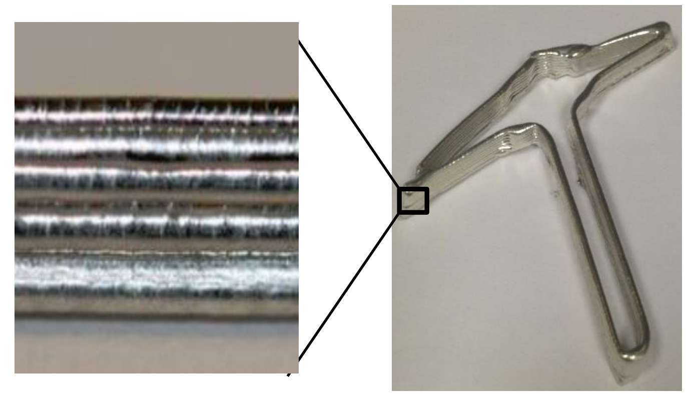
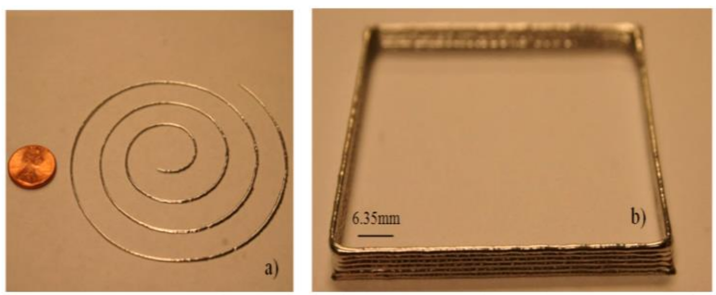
Modified Head

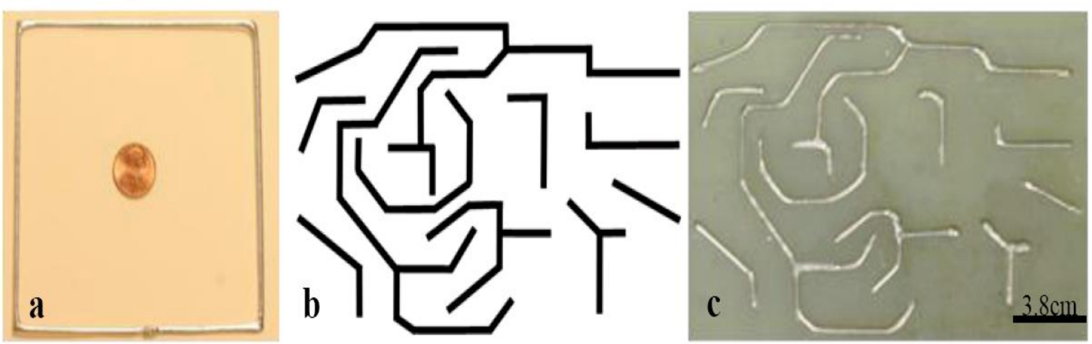


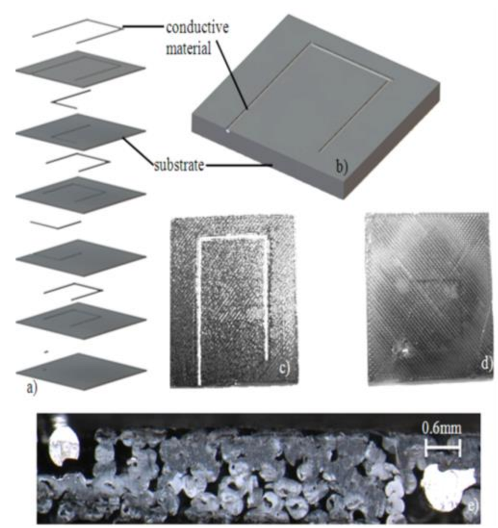
Stacked Layers



Consistent line widths







Mireles, Kim, Lee, Espalin, Medina, MacDonald, Wicker, "Development of a Fused Deposition Modeling System for Low Melting Temperature Metal Alloys," J. Electronics Packaging, 2013.

The Polymer/Ink Challenge

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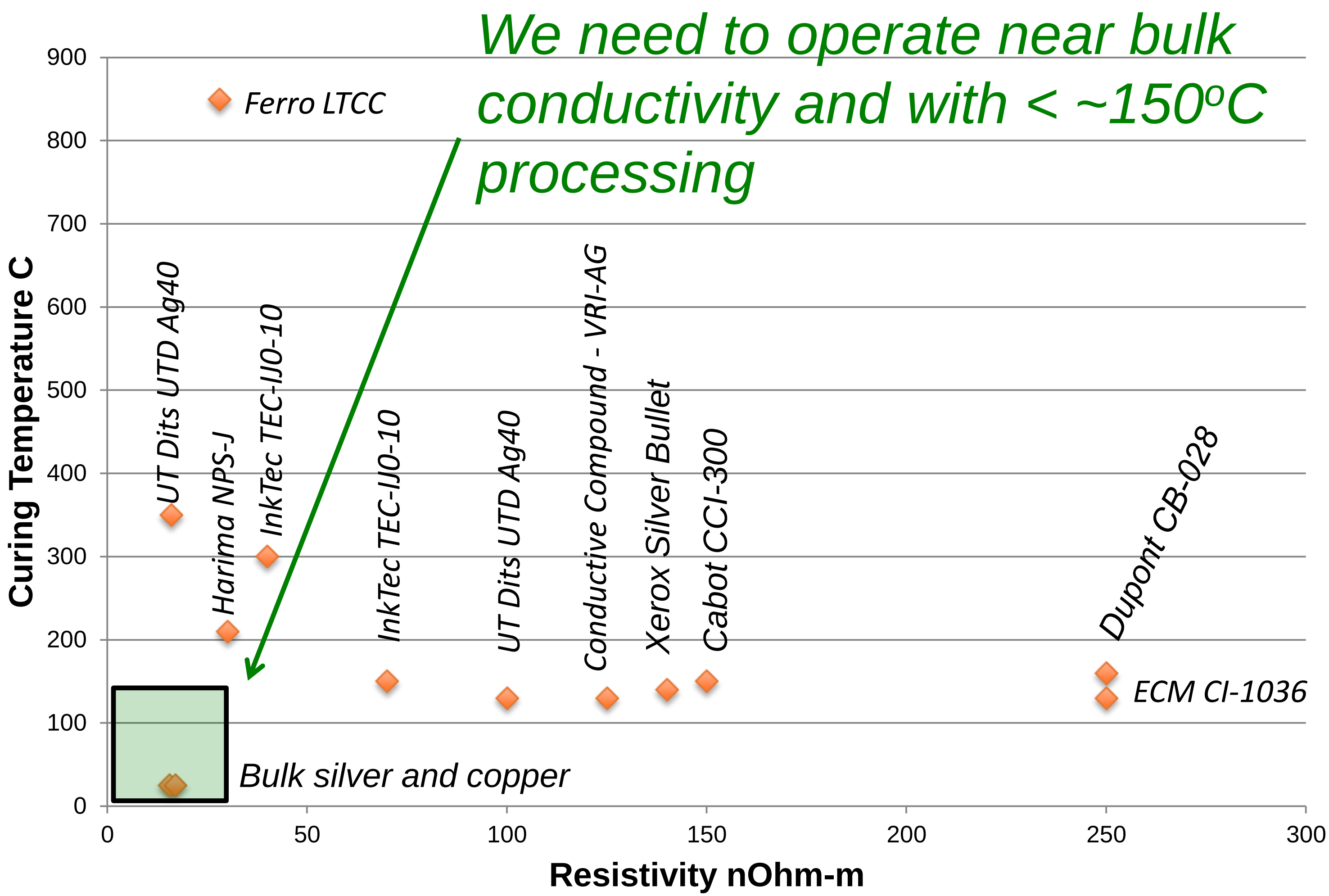

Our Ideal Scenario

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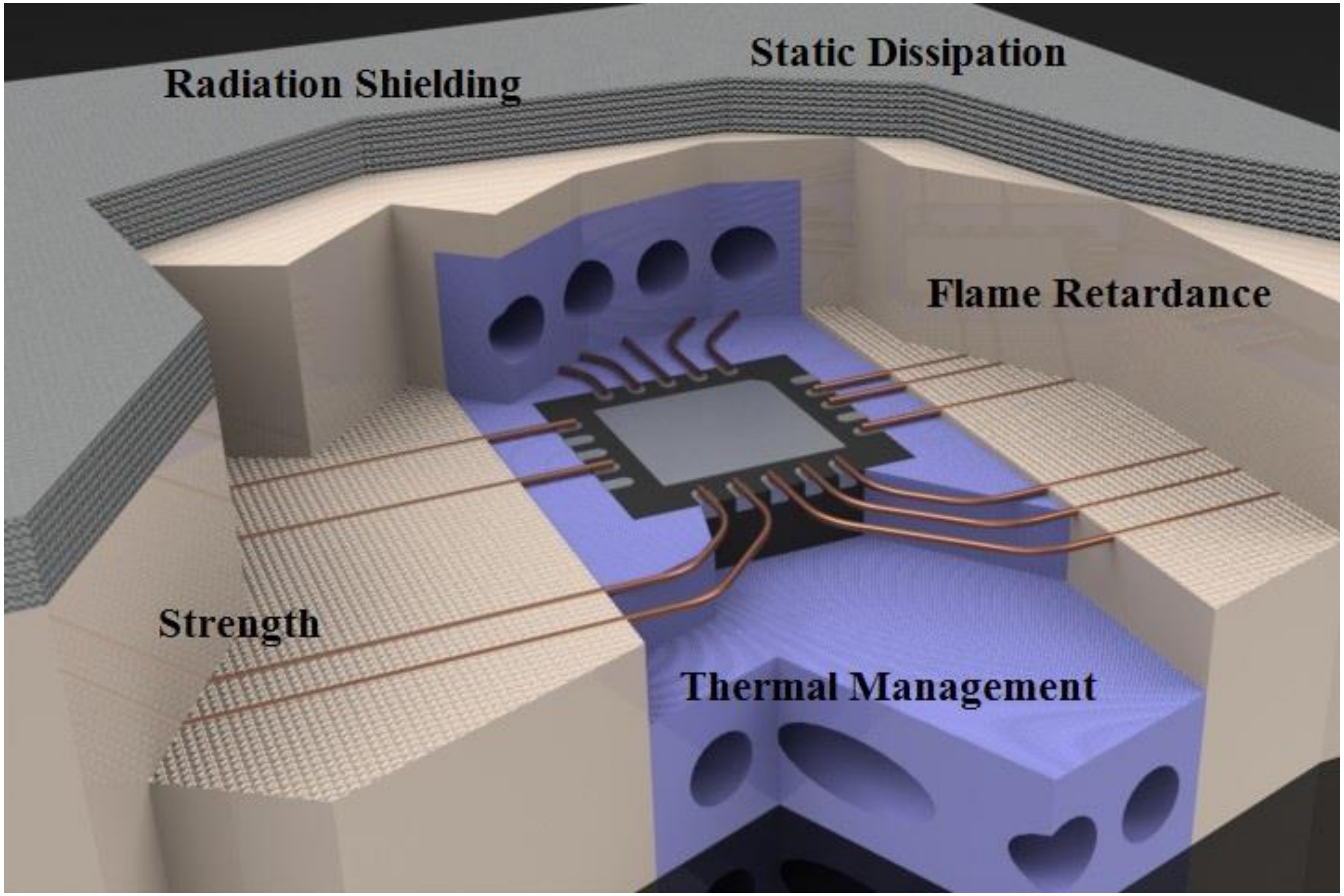
Multi-Material, Multi-Technology AM



Key Technologies – Research and Integration

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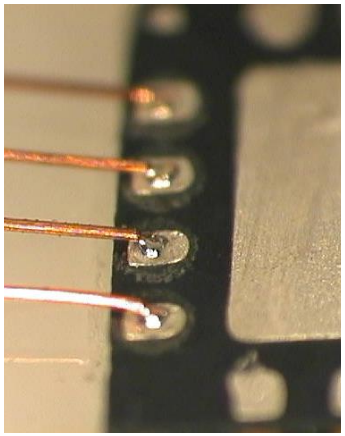
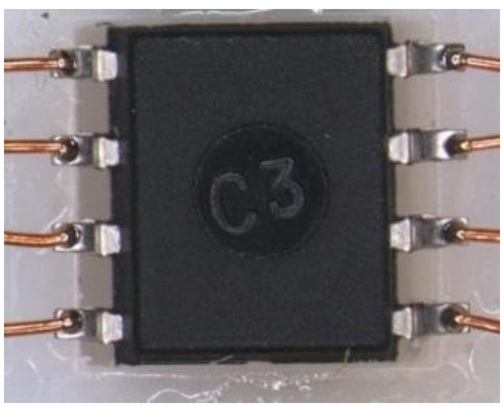
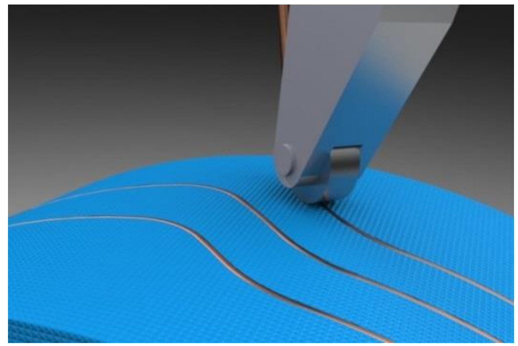
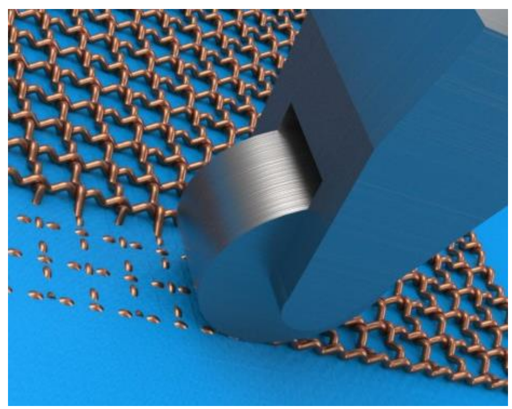


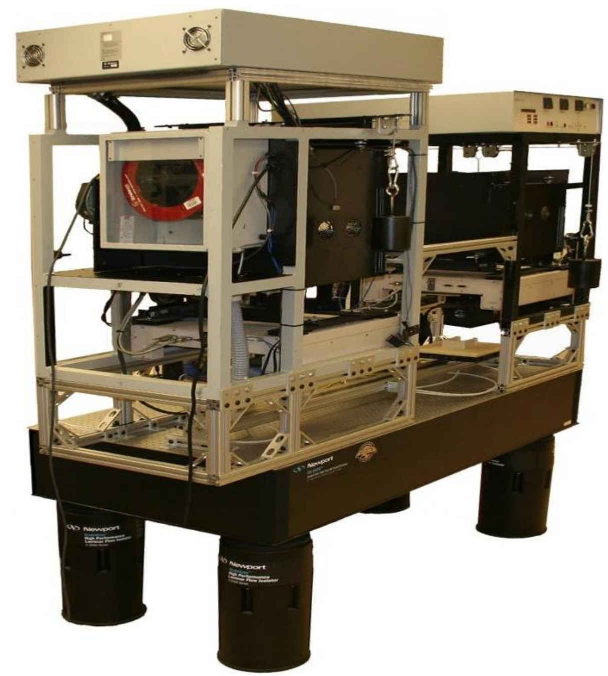


Laser Micro-Welding



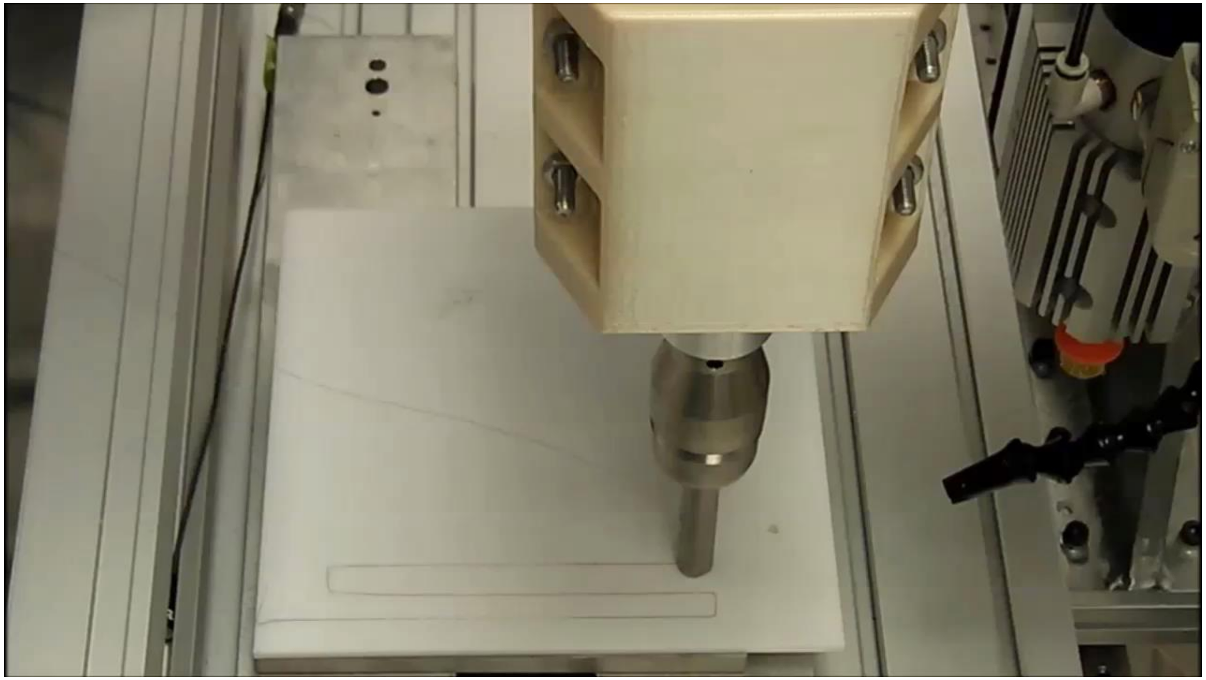


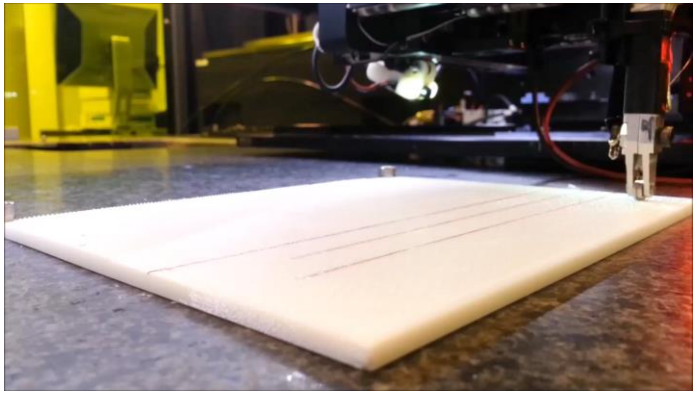
Wire Embedding

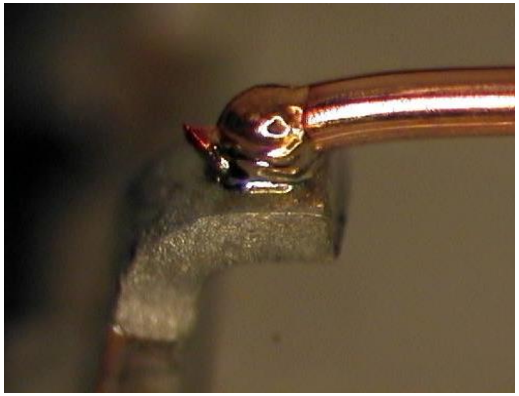


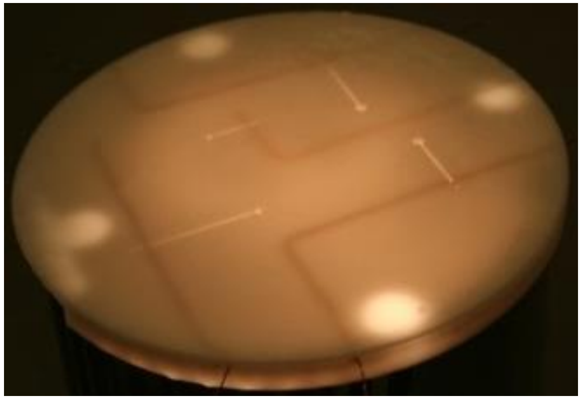
Integration in MM, MT FDM

Process Developments



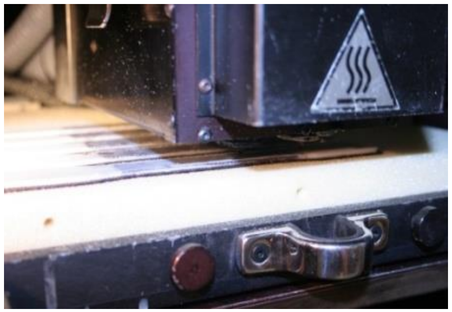
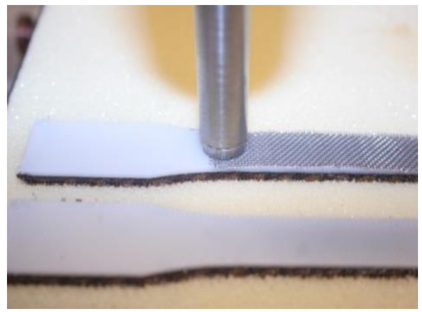
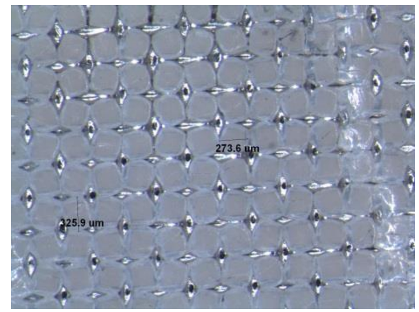


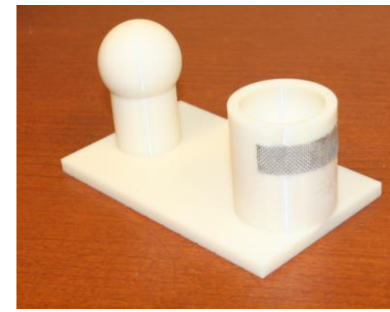




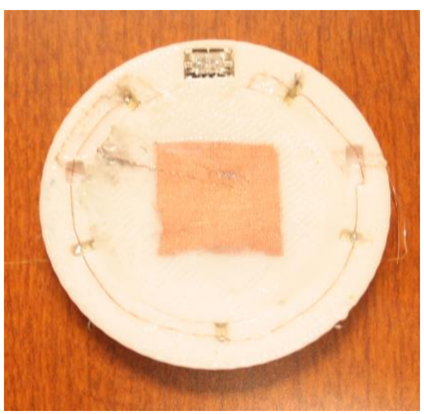
How about more than wire? Polymer-Metal Composites

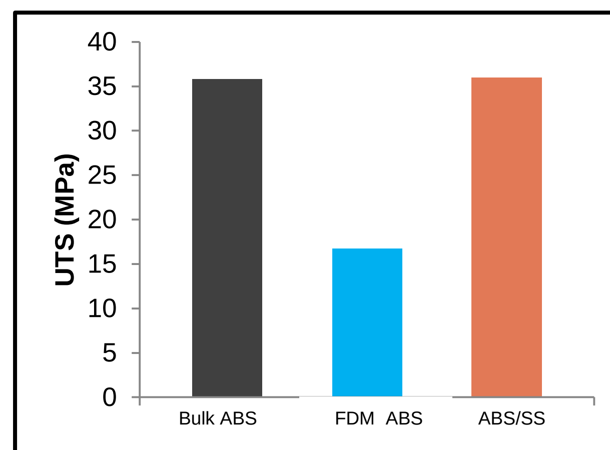
Mechanical: FDM + Mesh = Functional Composite




Electronics: Ground Planes, EMI Shielding, or Non-mechanical Switches





Multi^{3D} Technology

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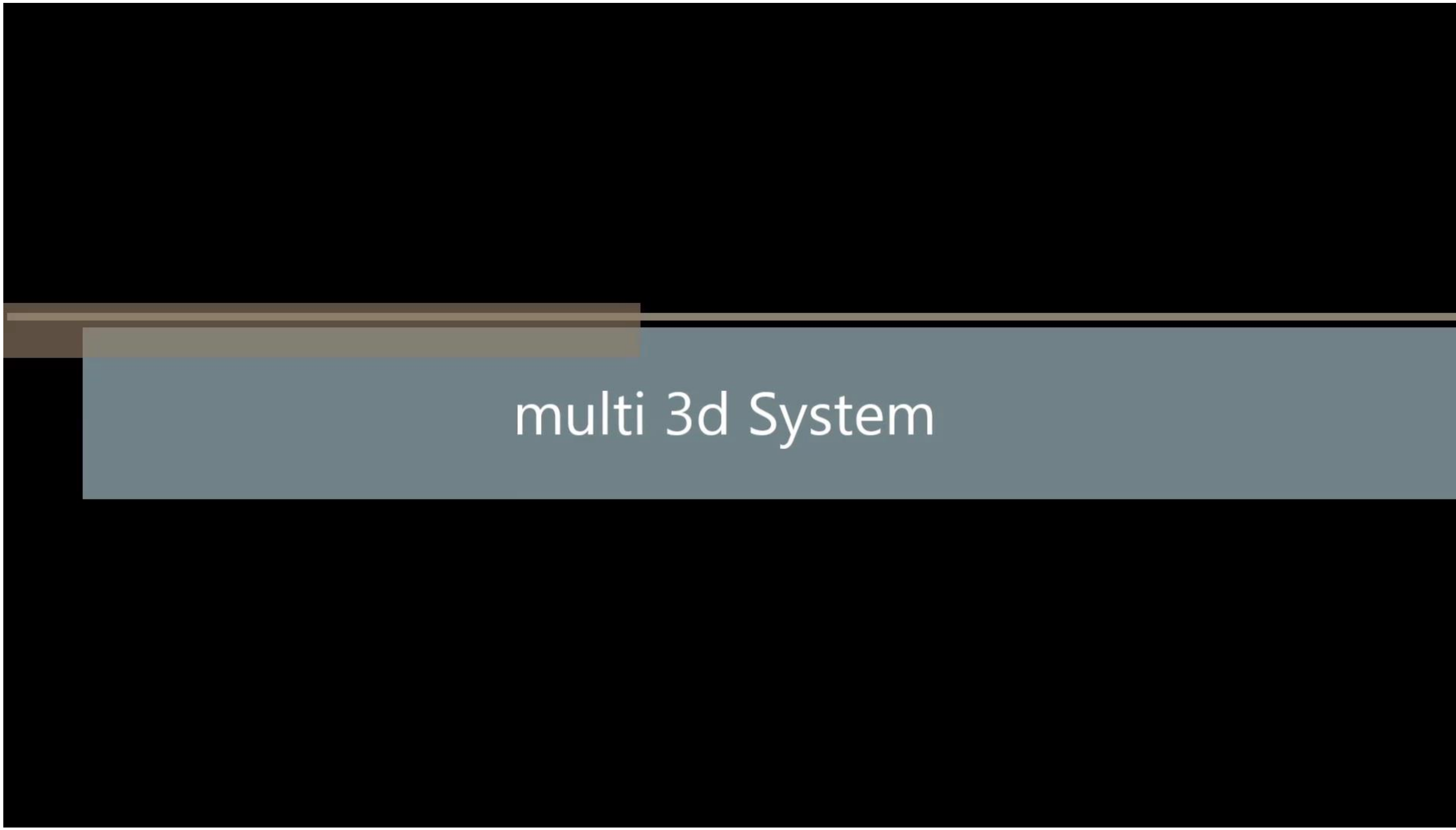

Printing / Packaging Functional 3-Phase Brushless DC Motor

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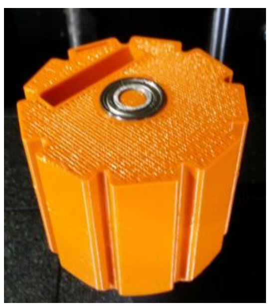
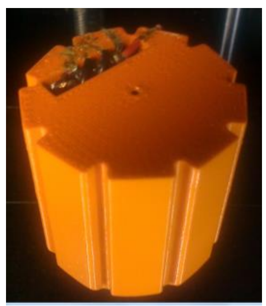
- Bearing (1)

- Magnets (2)

- Electro-Magnets (3)



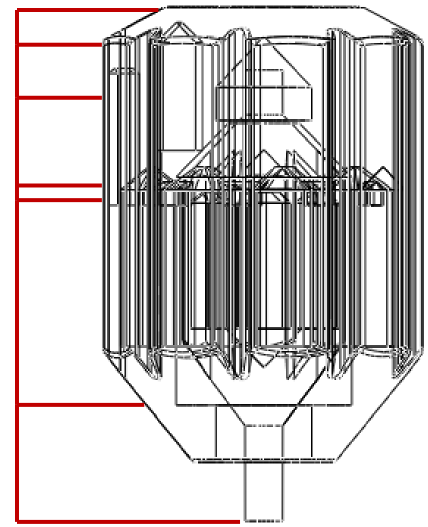
- Bearing (4)



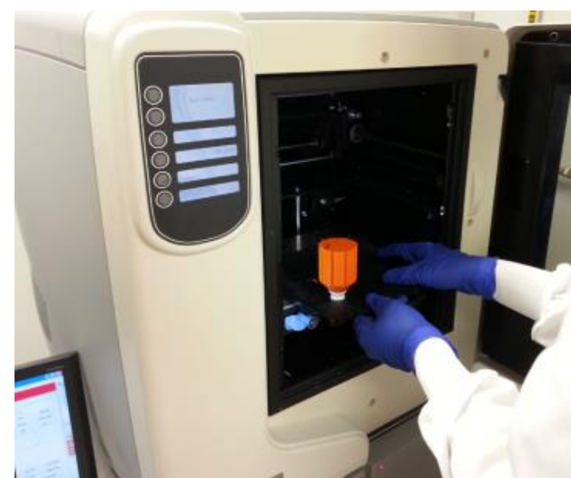
- Speed Controller (5)

- Finished Motor (6)

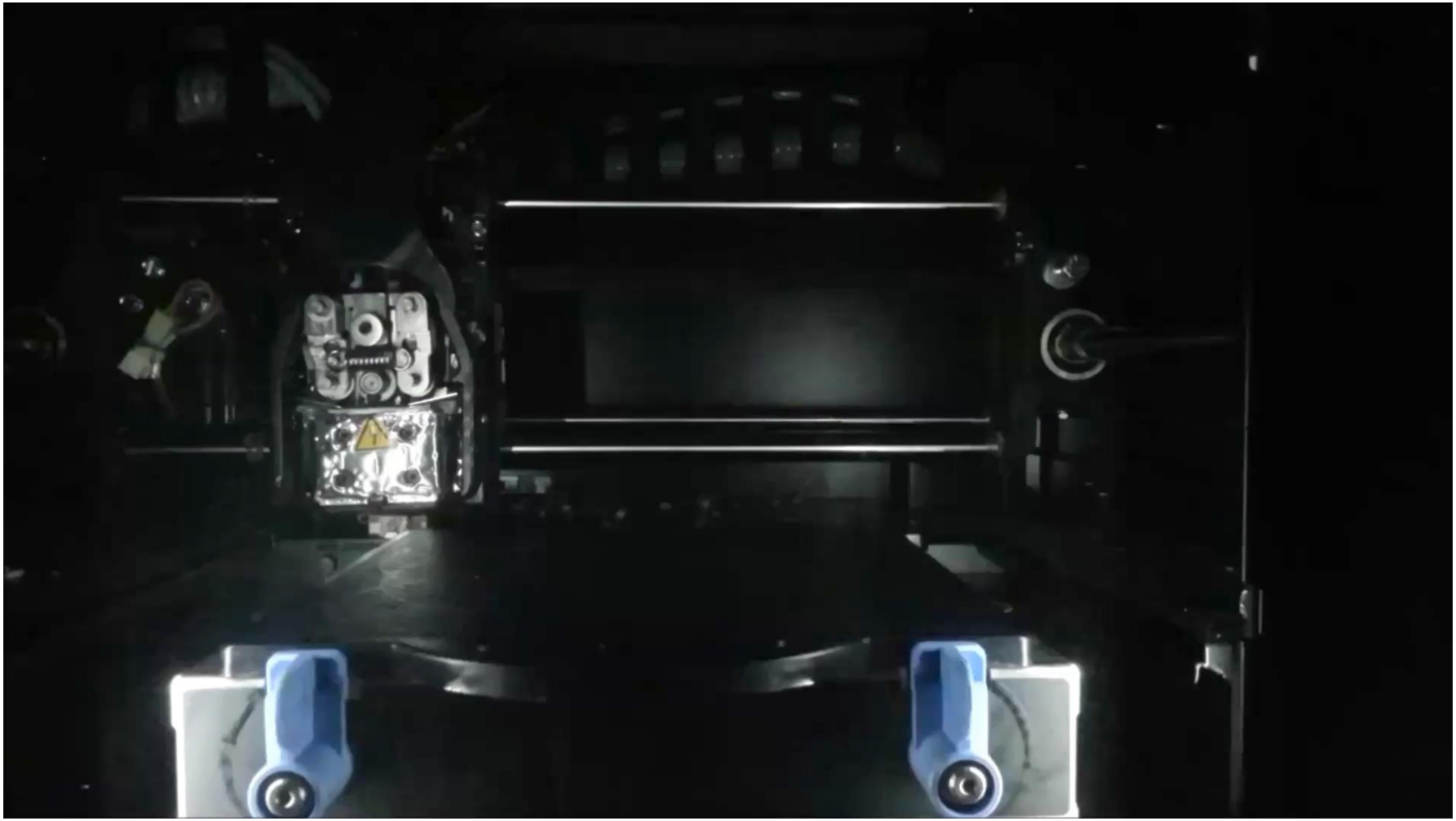
- Segment 6
- Segment 5
- Segment 4
- Segment 3
- Segment 2
- Segment 1



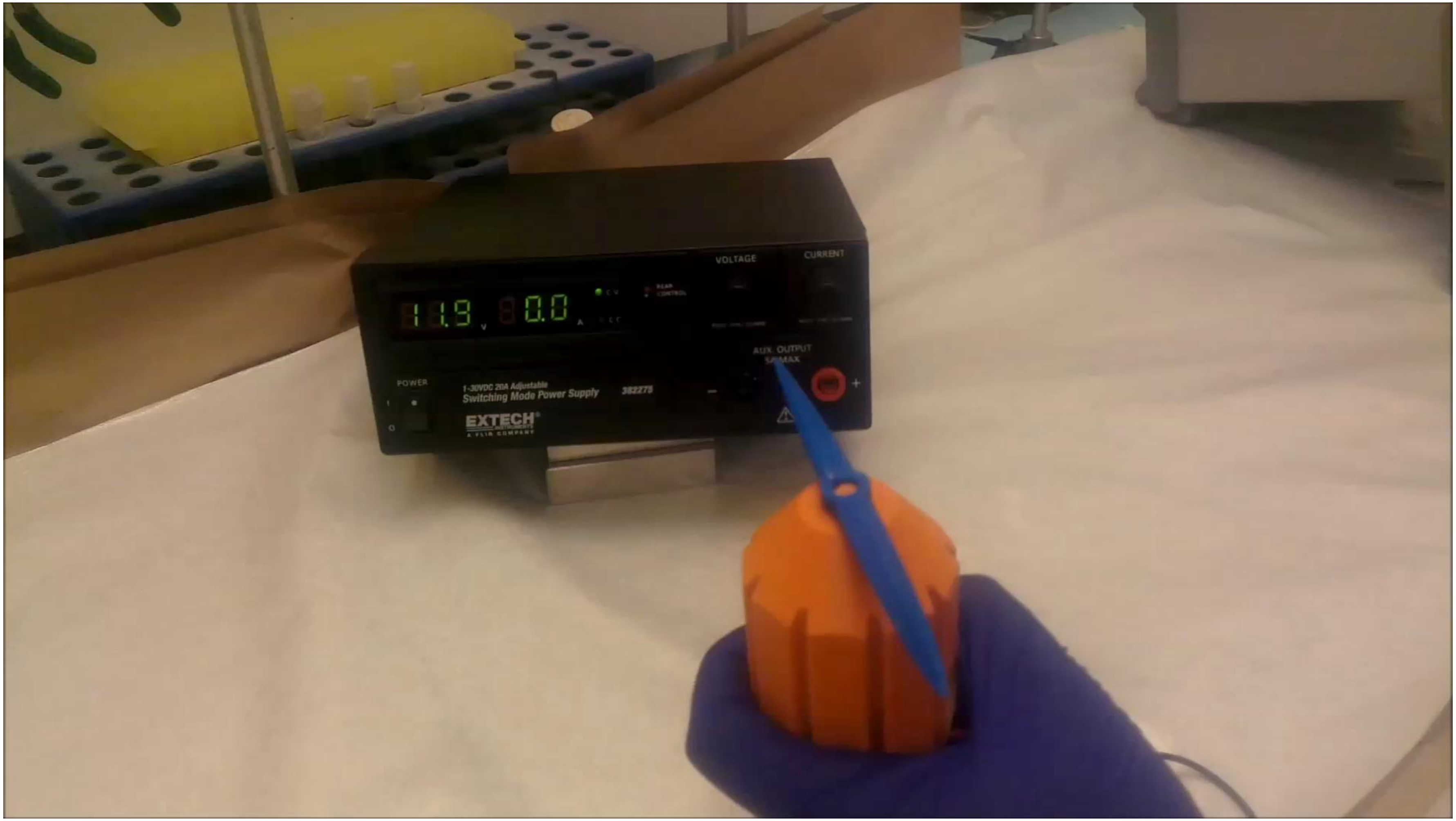
- Single build sequence – built all in a uPrint (break off support and motor works)
- Embedded components (2 bearings, 6 magnets, 9 electro magnets, electronic speed controller rated at 10 amps)
- Complete fabrication process requires ~7 hours



The Future: Printed / Packaged Electro-Mechanical Systems



The Printed Motor In Action



Possibilities with Metals

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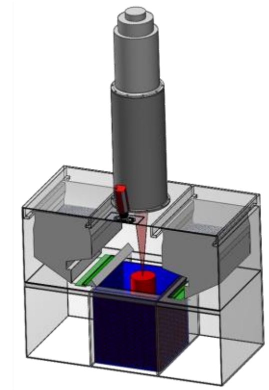
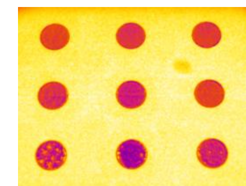
Electron Beam Melting (Powder Bed)

Arcam A2 with IR Camera and S12 High Temp

Closed-Loop Process Control





Mini-Vat (Materials Parameter Development)

Materials: Ti64, TiAl, TiNb, Inconel 625, Inconel 718, Rene, CoCr, Haynes, Copper, Tantalum, Niobium, Fe, and others (some proprietary)

Murr et al., "Metal Fabrication by Additive Manufacturing Using Laser and Electron Beam Melting Technologies," J. of Materials Science and Technology, 2012.

Our Goal: Full Spatial Control of Material Placement and Structure Creation

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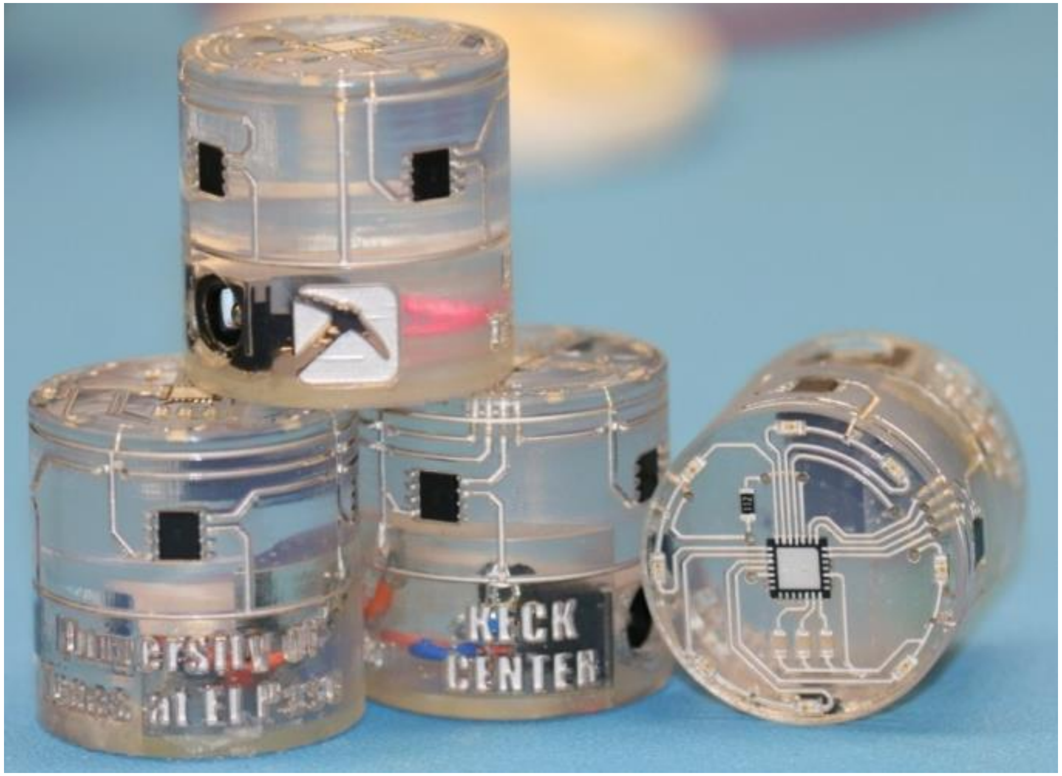

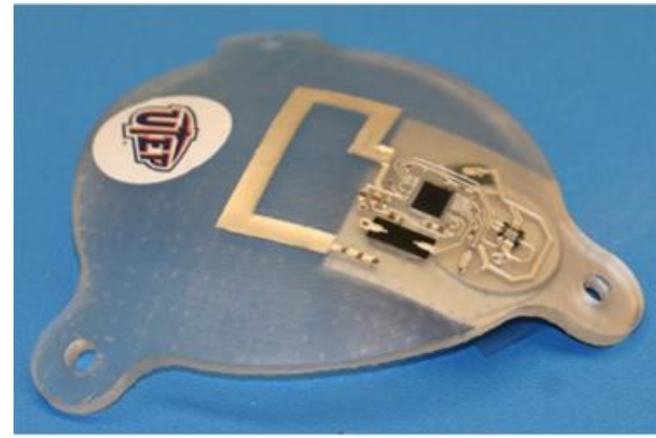

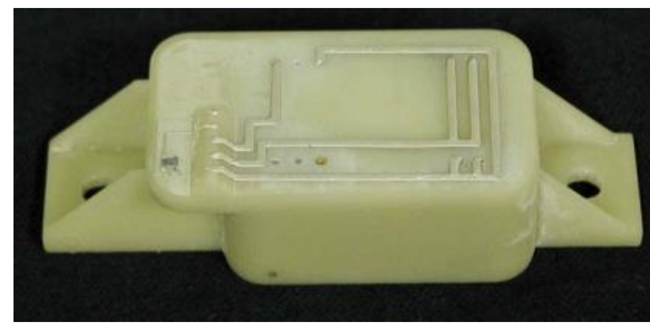

W.M. Keck Center for 3D Innovation: Research Group