Printing Multi-Functionality with Multi-Technology Additive Manufacturing

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Where is UTEP?

El Paso, Texas, USA
Keck Center in the Beginning (August 2000)
Keck Center: Key Initial Partnerships/Investments

Universities - National and International

Government Agencies, Private Foundations and National Laboratories

Sandia National Laboratories

W.M. Keck Center
FOR 3D INNOVATION

Dr. Edward Egbert, M.D.

Individual Supporters, Physicians and Surgeons

DSM Somos®
Keck Center: Continuously Expanding Productive Partnerships

Universities - National and International

Government Agencies, Private Foundations and National Laboratories

Industry

Individual Supporters, Physicians and Surgeons

Dr. Edward Egbert, M.D.

UTEP

W.M. Keck Center
FOR 3D INNOVATION
W.M. Keck Center for 3D Innovation

- 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

- Ceramics AM
- CNC
- Metals AM
- Research
- Chemistry
- Bio
- Entrance
- Polymers AM
- Testing
- EM
- Electronics
- ITAR/SCIF
- Microscopy
- Polymer Extrusion
Center Focus and Expertise

Mechanical

AM Technology Development

Advanced AM Applications

Engineered & Structured Materials

3D Structural Electronics & Printed Electromagnetics

Electrical

Metallurgical

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

Forged or Cast

Machined for Weight Savings

Designed for Additive Manufacturing
AM Advantage: Multi-functionality

Forged or Cast

Machined for Weight Savings

Fabricated with Optimized 3D Structuring of Materials

Optimized Antenna
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


U.S. Patents 7,556,490 and 7,959,847
Bio-fabrication

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

Micro-SL System with Multi-Material Capabilities

Multi-Technology: SL Integrated with Direct-Print

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

Advantages of 3D Structural Electronics

- 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

- 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

- 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

FDM and 3D Structural Electronics

Microelectronics – resolution requirements

Conductive inks – dispensing and curing

Final Performance
Advancements in FDM

FDM Filament Development

FDM Process Parameter Development

FDM Processing Optimization

Materials Characterization

Ultimate tensile strength (MPa)
Raster angle (degree)

- Standard/Default
- Optimized
- no gaps

~30% increase
FDM and Electronics

3D Printed CubeSat Module

Standard

Optimized
Ink Curing and Performance

Different In Situ Curing Strategies

Variable Power Supply

Printed Conductive Trace

Polymeric substrate

Ohmic Curing

Different Ink Morphologies

Nano

Micro

 Flake

Resistivity nΩ·m

Cabot CCI-300 Nanoparticle
DuPont CB028 Microparticle
Ercon E1660 Micro Flake
Min Ag Microparticle
Min Ag Nanoparticle
Aluminum
Copper
Silver
Gold

Cured at 250°C
160°C
138°C
850°C
250°C

Are conductive inks adequate?

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

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

We need to operate near bulk conductivity and with < ~150°C processing.

Bulk silver and copper
Our Ideal Scenario

Multi-Material, Multi-Technology AM

Radiation Shielding
Static Dissipation
Flame Retardance
Strength
Thermal Management
Key Technologies – Research and Integration

Laser Micro-Welding

Wire Embedding

Integration in MM, MT FDM
How about more than wire?
Polymer-Metal Composites

Mechanical: FDM + Mesh = Functional Composite

Electronics: Ground Planes, EMI Shielding, or Non-mechanical Switches
Multi3D Technology

multi 3d System
Printing / Packaging Functional 3-Phase Brushless DC Motor

- Bearing (1)
- Magnets (2)
- Electro-Magnets (3)
- Bearing (4)
- Speed Controller (5)
- Finished Motor (6)

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
Electron Beam Melting (Powder Bed)
Arcam A2 with IR Camera and S12 High Temp

Closed-Loop Process Control

Mini-Vat
(Materials Parameter Development)

Possibilities with Metals

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

Our Goal: Full Spatial Control of Material Placement and Structure Creation
W.M. Keck Center for 3D Innovation: Research Group