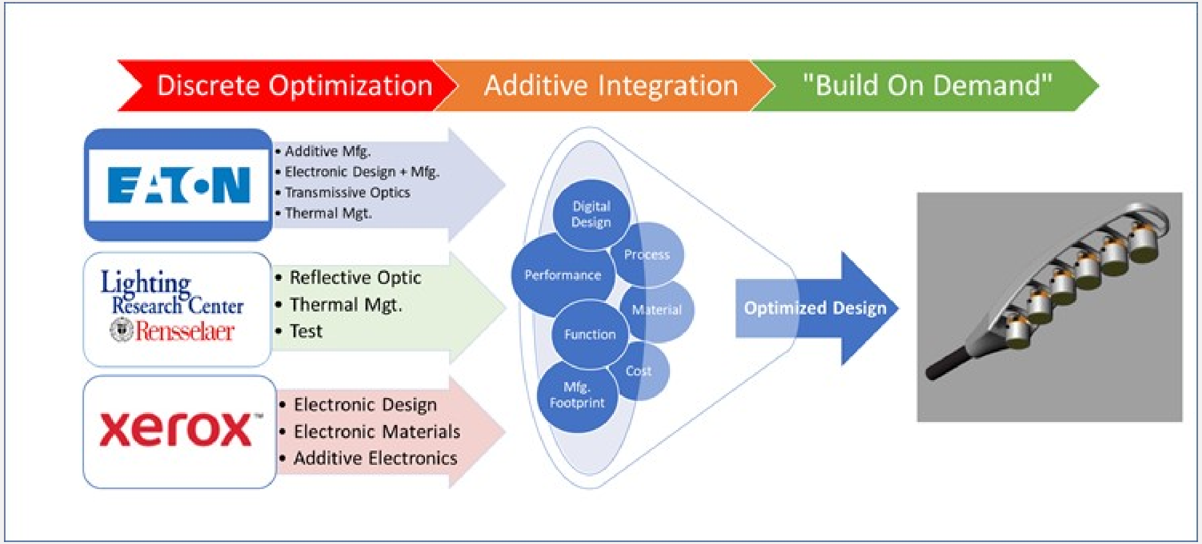

Transforming Solid State Lighting with Additive Manufacturing

Additively Manufactured Luminaire: Process and Material Challenges (things that keep me awake at night)

John Trublowski – Eaton Corporation (Award: DE-EE0008722)

DOE Workshop, San Diego, CA Jan. 28-30, 2020

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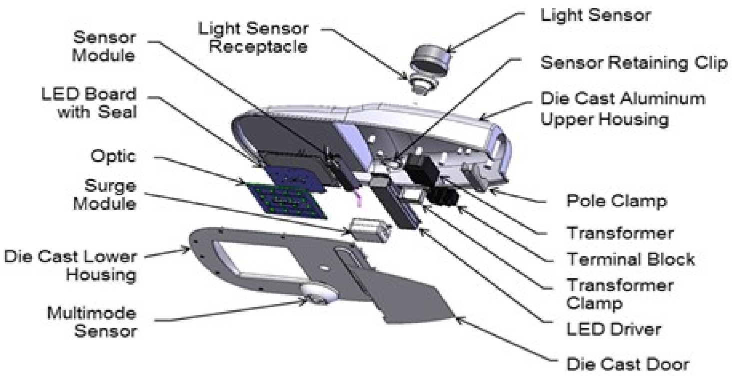
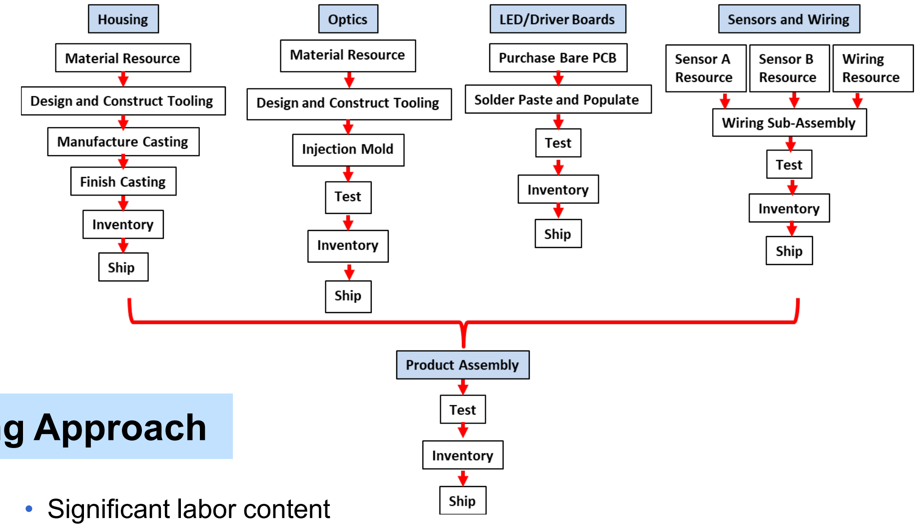
Luminaire Assemblies: Where are we today?

Typical Roadway Assembly



Typical Luminaire Manufacturing Flow



Traditional Manufacturing Approach

- Assembly line model
- Complex assemblies
- Many designs / components

- Significant labor content
- Complex supply chain
- Large inventory
- Long cycle times
- Long time to market

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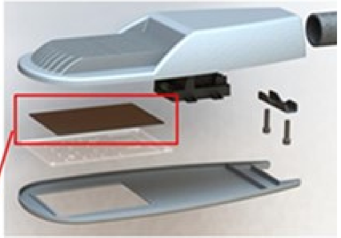
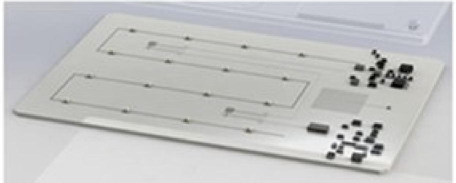
Luminaire Assemblies: Where do we want to be?

Integrated Roadway Concept

Eaton Concept Prototype (2017)*

- Fully printed, integrated circuitry with LED, driver, sensors and antennas
- Minimal part count
- Simplified assembly





Integrated Manufacturing Flow

Fully Integrated CAD Design
↓
Machine Download and Debug
↓
Manufacture AM Luminaire
↓
Post Process
↓
Test
↓
Inventory
↓
Ship

Manufacture AM Luminaire draws on:
- Metal Material Resource
- Polymer Material Resource
- Optical Material Resource
- Electronics and Sensor Material Resource

Fully Integrated Manufacturing Approach

- "Print on demand" model
- Few components and assemblies
- Integrated mechanical/electronics

→

- Reduced operations and mfg. footprint
- Consolidated supply chain
- "Near" zero inventory
- Faster time to market

* **Print-based Manufacturing of Integrated, Low Cost, High Performance SSL Luminaires**, **Final Report,** DoE/SSL Funded Project, **Contract Number: DE-EE0006260, 2016**

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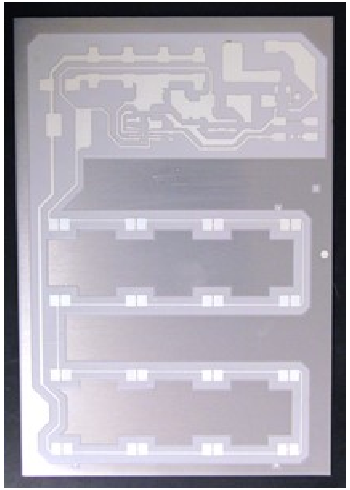
Key Additive Manufacturing (AM) Elements to Consider

Mechanical Housing

Thermal Management

Electronics



Optics

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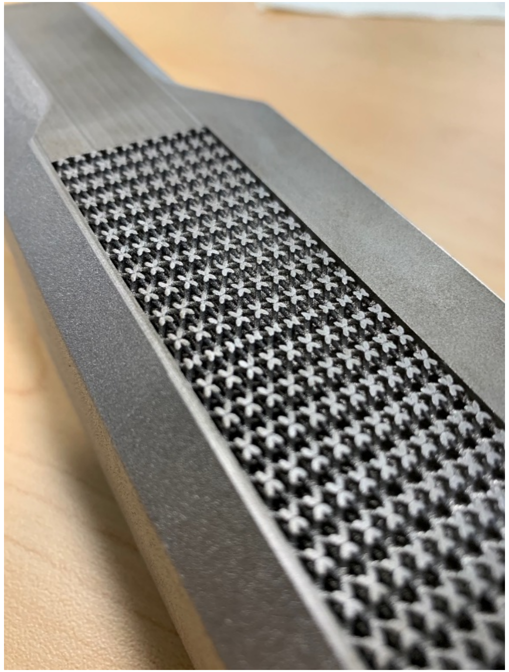
Mechanical Housing

- Integrate mechanical features (minimize SKU's)
  - Heat sink
  - Mounting and adjustment hardware
  - Fasteners
  - Gaskets
- Utilize AM techniques to reduce material and weight
  - Skins on scaffolds
  - Vary cross section based on requirements
- Post processing
  - Cost impact so minimize
- Polymer or Metal?
  - Weight, cost impact
  - Environmental exposure requirements (polymer may be better from a corrosion perspective)
  - Polymer may be printed on metal (not vice versa)



Lattice construction for reducing materials and weight (Eaton Corp.)

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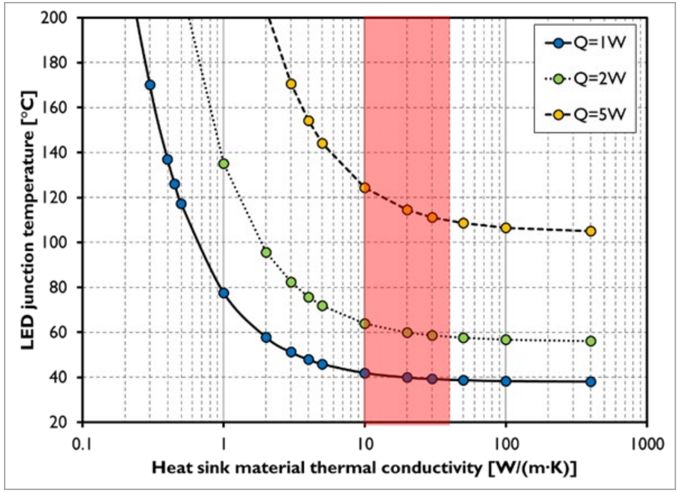
Thermal Management

- AM material properties may differ from “wrought”
  - Porosity effects
  - Thermal properties may differ as a function of print direction
  - Filler segregation (in polymers)
- Minimal manufacturing constraints
  - Not limited by traditional heat sink fabrication methods
  - May require some post processing to achieve full properties
- Polymer or Metal?
  - Validate LED junction temperature with thermal simulation
  - New materials emerging every day
    - Metals: Al alloys, Cu, Ni super alloys, Ti, steels
    - Polymer with nano-fillers: ceramic, Carbon, nano-tubes (alignment still an issue), Cu

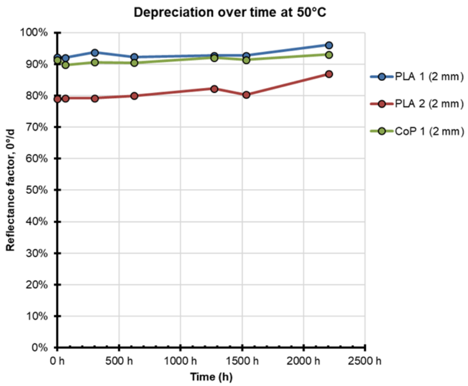
Material	Thermal Conducvtivity ($Wm^{-1}K^{-1}$)	Comments
Cast Aluminum	90-160	Published but actual = 80-90
Printed Al Alloy	34 - 60	As Printed
Printed Al Alloy	42- 72	Estimate, Post Process 1
Printed Al Alloy	60 - 102	Estimate, Post Process 2
Thermally Conductive Polymer A	3.5	Molded
Thermally Conductive Polymer A	3.5	Measured in direction of print
Thermally Conductive Polymer A	2.5	Measured normal to print direction

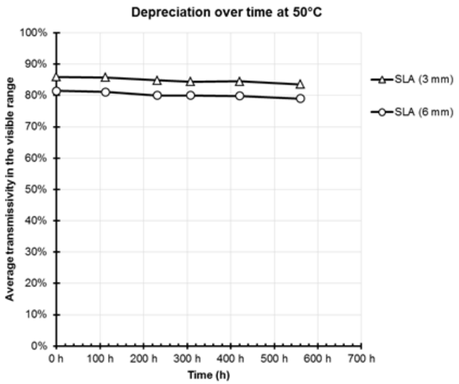


Estimated LED junction temperature based on thermal resistance model (1-5 W LED thermal load on a 10×10 cm² x 2.5 mm thick sink).

Optics

3D Printed Optic for Modular Concepts





3D Printed samples long-term optical testing results under 50°C elevated temperature (reflective on right and transmissive on left)*

- Material choices still limited
  - Metals
  - Polyurethanes, acrylics, some polycarbonate
  - Silicones emerging
- Optic design
  - Optical properties still behind traditional methods
  - Reflective ahead of transmissive (material constraint)
  - Complexity typically not an issue
  - Surface finish and color capability still limited
- Environmental exposure
  - Temperature
  - UV exposure still a problem for some materials

(*O. Privitera, Y. Liu, I. Perera, J. Freyssinier, N. Narendran, "Optical properties of 3D printed reflective and transmissive components for use in LED lighting fixture applications," Proc. SPIE 10940, Light-Emitting Devices, Materials, and Applications, 109401X (2 April 2019)

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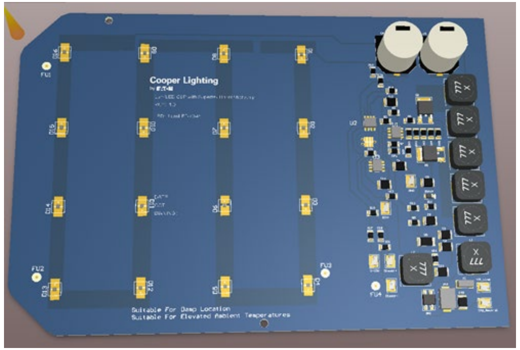
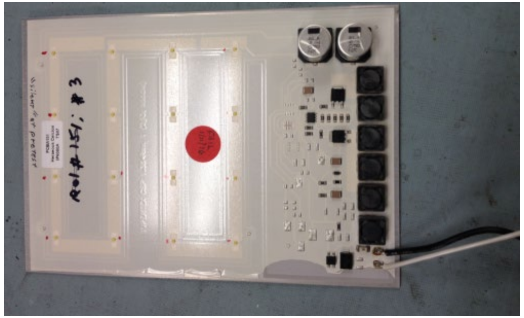
Printed Electronics on AM Structures

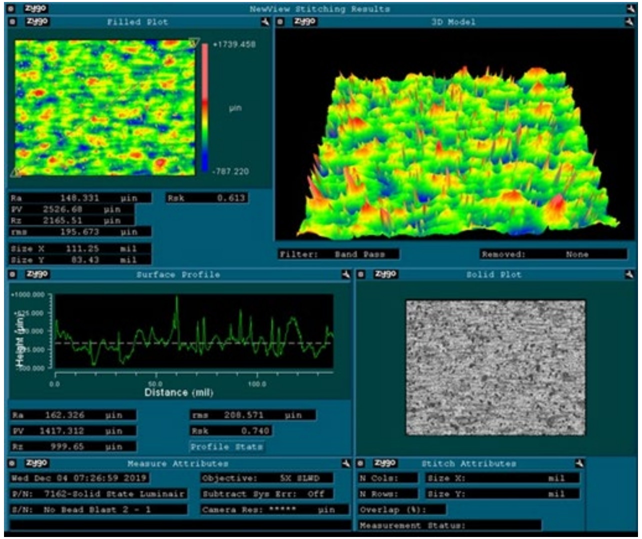
- Materials
  - Many choices but varied properties
    - **Conductors:** Silver, Copper, **Dielectrics:** polymer and inorganic, **Resistors**: Some availability but chip components are more cost effective
  - Low temperature vs high temperature processing
  - Compatibility with AM substrate materials
    - Adhesion, Surface finish, Thermal expansion
  - Design rule development (geometry vs current carrying)
- Take advantage of AM processing
  - Thickness adjustment for high and low current
  - Integrate wiring wherever possible
  - Environmental protection on electronics may be required
- Interconnects
- Component attach: Solder or Electrically Conductive Adhesive?





Printed electronic design (top) for Roadway application and functional prototype (from DOE Project # DE-EE0006260)

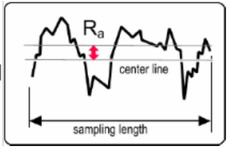
Printed Electronics and Surface Finish



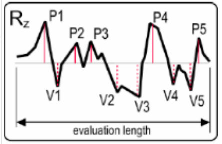
Surface scan of Printed Electronics area on metal AM sample

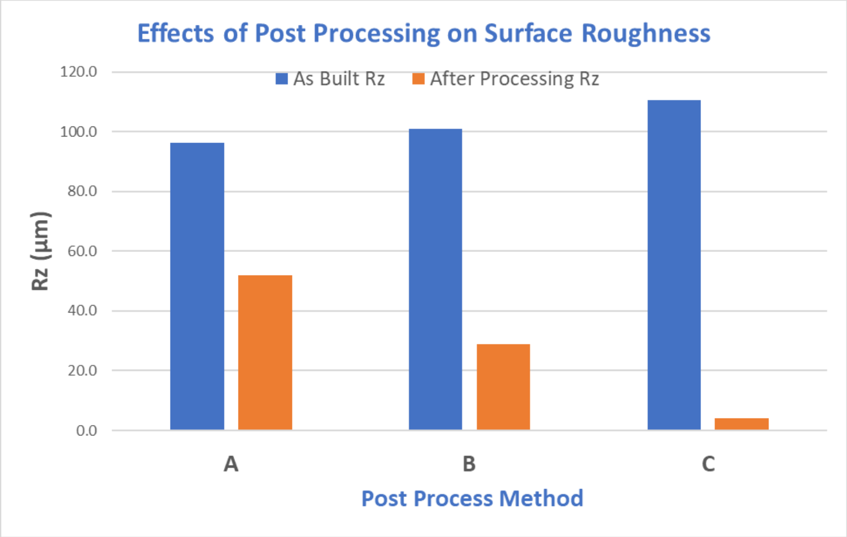
- Ra = 162 µin (4.12 µm), Rz = 999 µin (25.39 µm)
- Rz is a better measurement for printing electronics
- If Rz is too high, shorting may occur through dielectric isolation layers

Ra = average abs. value of all peaks and valleys in scan area



Rz = average abs. value of 10 highest peaks and 10 lowest valleys in scan area





Post processing can be used to improve surface finish to acceptable level

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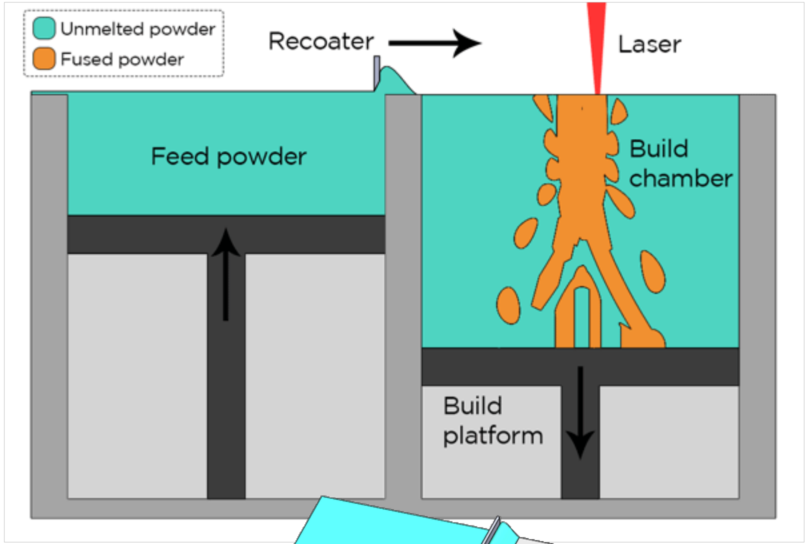
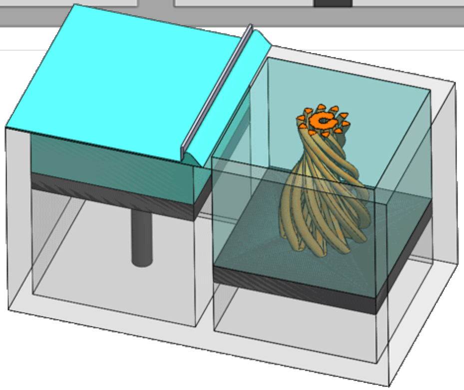
AM Metal Fabrication: L-PBF Process Example

- Laser Powder Bed Fusion (L-PBF) is the additive manufacturing industry standard for producing high-density, precision metal parts.
- Metal powder is laser welded layer-by-layer in a controlled process
- Common materials: Stainless steels, tool steels, cast aluminum alloys, cobalt chrome, Inconels, titanium alloys, etc.
- Typical process time hours to days or less (design dependent)





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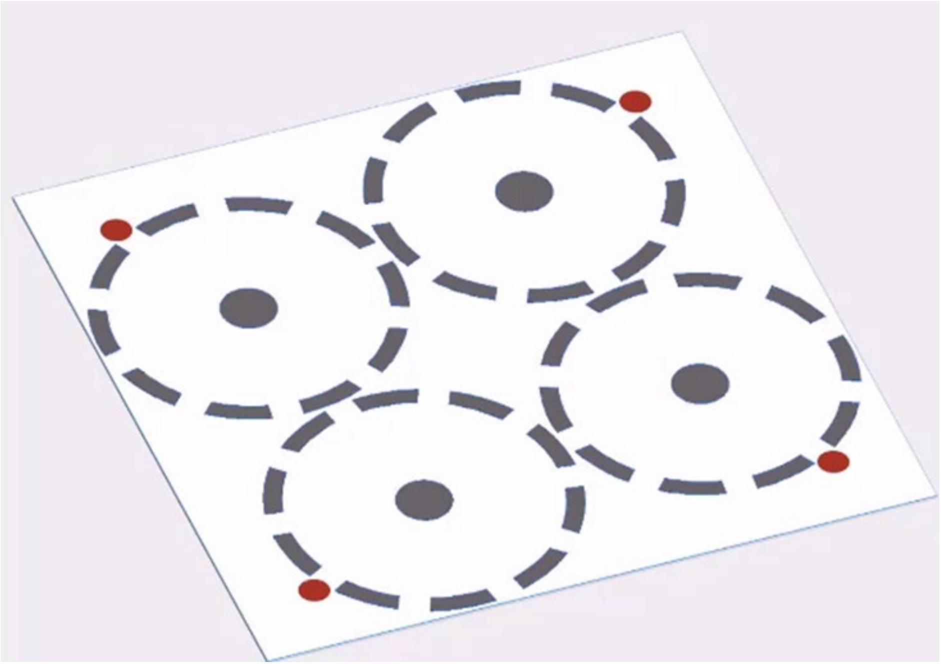
AM Metal Fabrication: L-PBF Process Example

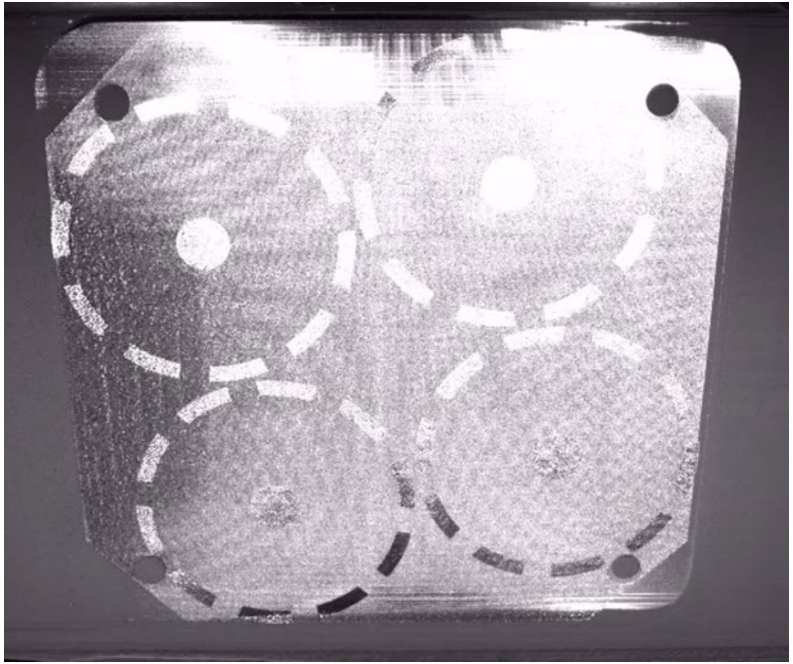
- Test structure for printed electronics processing
- Development of design rules for printing on 3D surfaces
- Explore placement of LED’s at different angles and levels within the structure
- Fabricated using L-PBF process (Aluminum based alloy)

Printed electronics test structure (~ 4” dia. X 5” height, 0.25” wall thickness)

AM Fabrication of 3D Printed Electronics Test Structure (Time Lapse)



CAD Geometry



Print Layer Progression

Questions

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