Goodman Technologies, LLC

TECHNOLOGIES, CERTIFIED COACH, B2B M&A

"OUR BUSINESS IS TO HELP YOU SOLVE YOUR PROBLEMS"

3D Printed Silicon Carbide Scalable to Meter-Class Segments for Far-Infrared Surveyor **NASA Contract NNX17CM29P**

SPIE Mirror Technology Days

November 14, 2017

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SPIE. Fellows

- **Historical Accomplishments Prior to July 2016**
  - Provided Breakthrough Technologies in Dimensionally Stable CMCs for NASA and MDA for Space and Aerospace Applications
  - Lead Materials Process Development for Uncooled Optics for High Energy Laser Systems (SBL, THEL, ABL, etc.), FSMs, Deformable Mirrors
  - Telescopes for Space and Airborne Applications
  - Survivable Technologies for Cryo, Space, Nuclear, Laser
- **Goodman Technologies LLC (GT)**
  - 3D/AM Technology> Ceramics & Ceramic Matrix Composites
  - Coaching> Performance & Results for Business/Individuals
  - Mergers & Acquisitions, Growth Capital for Middle Market

OUTLINE

- **Univ of Hawai'i (Minority Serving Institution)**
  - Mehrdad Nejhad, Ph.D., Professor, Past-Department Chair M.E.
  - Founding Director: Hawai'i Nanotechnology & Renewable Energy, Composites, & Smart Structs. Labs. , Associate Editor: Journal of Thermoplastic Composite Materials
- **Small Business Partners:** Materials and Processes
- **New Mexico Small Business Assistance (NMSBA) Grant**
  - **Backreach to Sandia National Laboratory**
  - Ceramics, CMCs & Multiple Types of Additive Manufacturing & 3D Printing

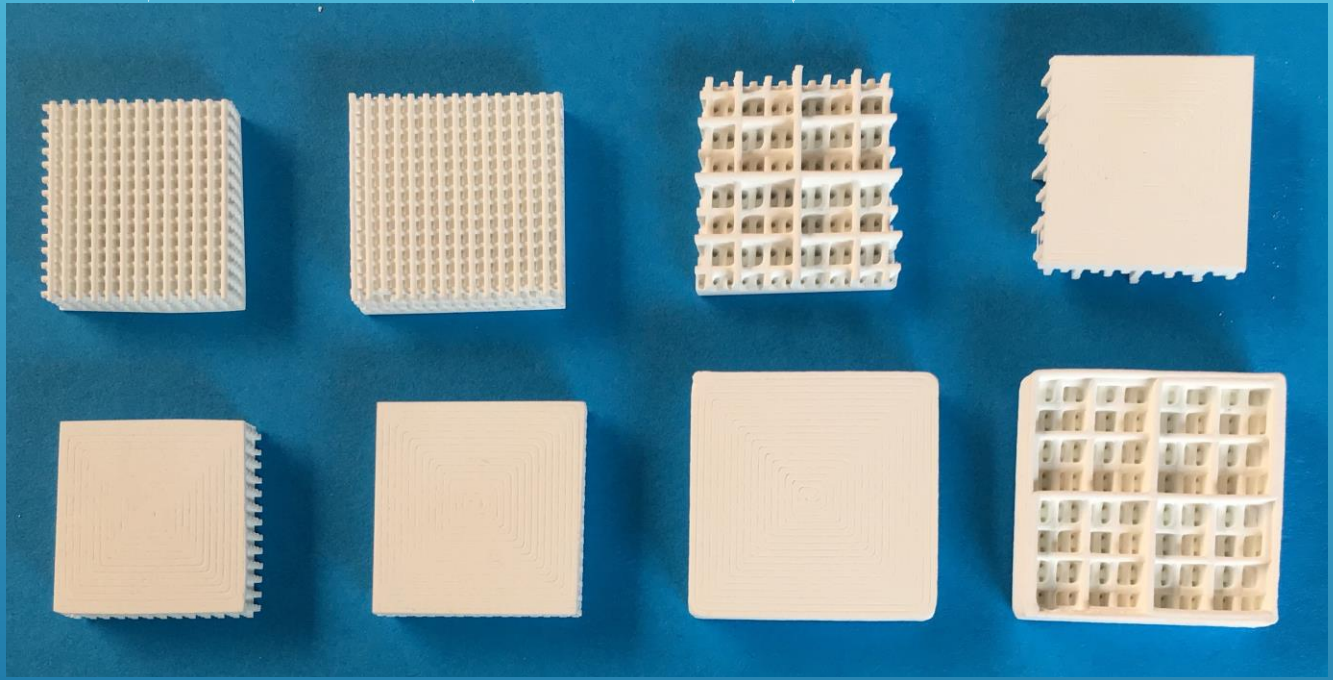
KEY PARTNERSHIPS IN ACADEMIA, INDUSTRY AND RESOURCES OF NATIONAL LABORATORY

Goodman Technologies, LLC

- **IRD Analysis for 1.5-meter SiC Segment showed:**
  - If you Print on Ground: Areal density of 7.75 kg/m^2
  - Print in Space → 1 kg/m^2
  - Cost to Print of \$60K/segment → Space Maybe \$10K
  - Optical Surface tailorable to nanometer-scale tolerances
  - Encapsulated lattice construction provides uniform CTE throughout the part for dimensional stability, incredible specific stiffness, and the added benefit of cryo-damping. GREAT FOR MIRRORS AND STRUCTURES.
  - Process allows direct embedding of electronics for active structures and segments, and the potential for actively cooling with helium for unprecedented low emissivity and thermal control (Analogous to the SLMS™ Technology Developed and Proven by Goodman & Jacoby 1998-2007)
  - Process highly-suitable for printing mirrors in micro-gravity
  - Provisional Patents Filed

0.5-m legacy SLMS

RESULTS OF GT INTERNAL RESEARCH AND DEVELOPMENT



FEASIBILITY OF PRINTED CERAMIC MIRROR SUBSTRATES DEMONSTRATED JULY 2016

- **NASA Contract NNX17CM29P "*3D Printed Silicon Carbide Scalable to Meter-Class Segments for Far-Infrared Surveyor*"**
- **Demonstrate feasibility of 3D Printed low areal cost, ultra-lightweight mirrors and structures**
- **Technology Development Roadmap shows production of 1st meter-class mirror segments by 2020 Decadal Survey**
- **1.5-meter hexagonal SiC segments will meet or exceed all NASA requirements for the primary mirror of a FIR Surveyor such as the Origins Space Telescope (OST), and may also provide a solution for the LUVOIR Surveyor**
- **New Technology Called RoboSiC™**

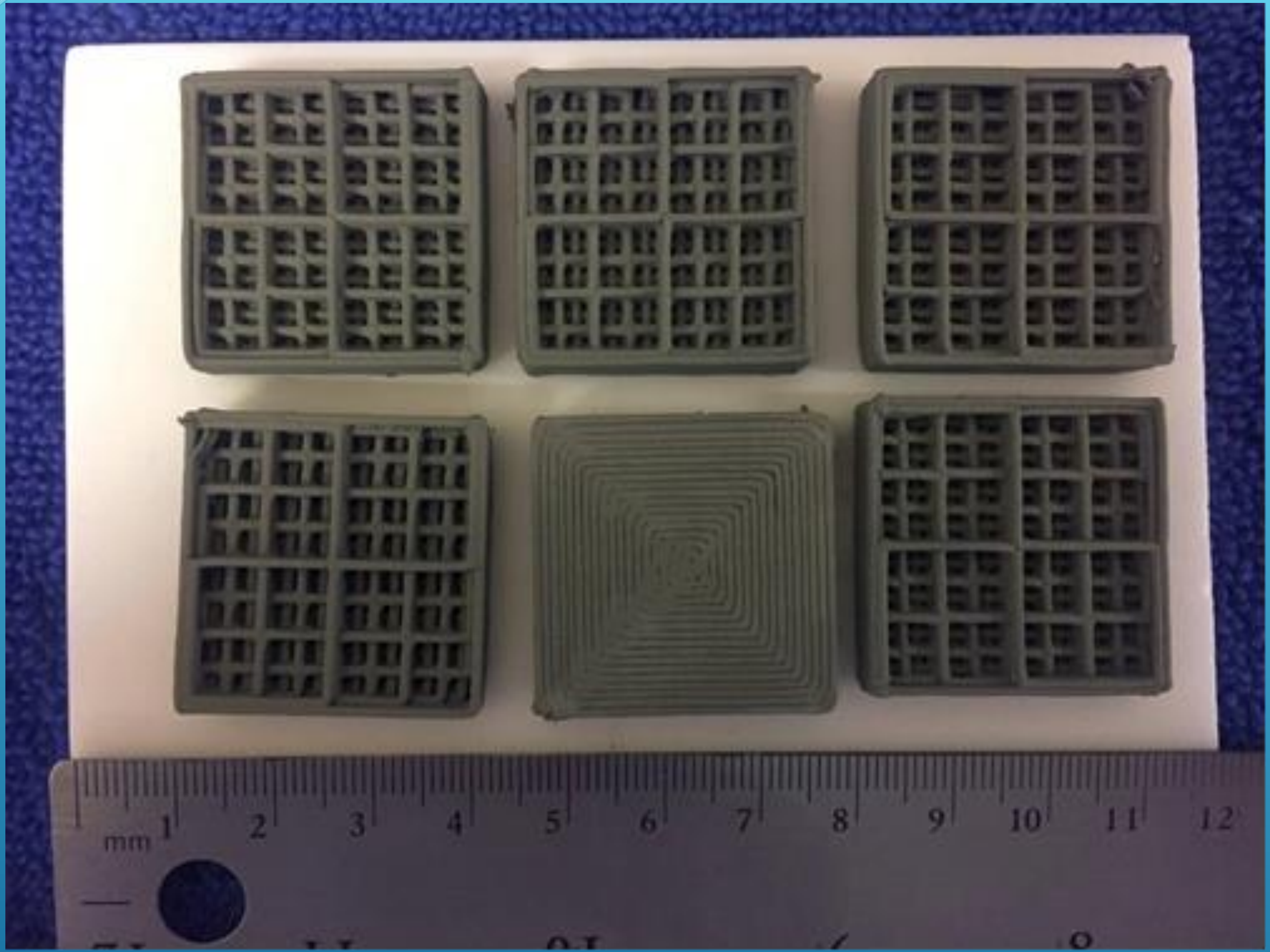
NASA AWARDS GT PHASE I SBIR

- NASA Astrophysics Division Roadmap Enduring Quests – Daring Visions builds on the 2010 Decadal Survey and includes near-term, formative (10-20 years – notional Surveyor missions) and visionary (20+ years – notional Mapper missions).
- Assuming a 20-m aperture Far-Infrared Surveyor (Origins Space Telescope), a 16-m aperture LUVOIR Surveyor, and 500 m^2 collection area for the ExoEarth Mapper, then at least 1015 m^2 of mirrors are required by NASA in the next 30 years.
- At the NASA target price of \$100K/m^2 this represents a marketplace totaling over \$101M for the Mirrors alone .

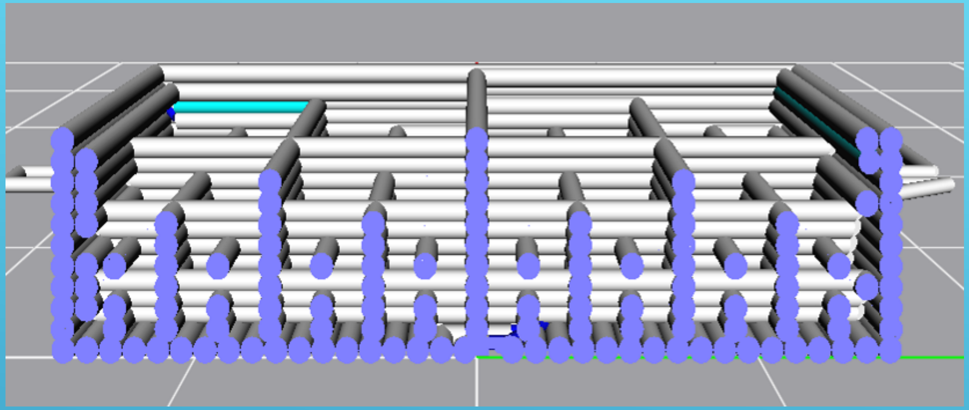
NASA COMMERCIAL APPLICATION

In Phase II this unit will be configured to produce multiple Meter-Class Optical Substrates.

SCALABLE TO LARGE PLATES/DEPTH 1.2 X 1.2 METER PROTOTYPE MACHINE



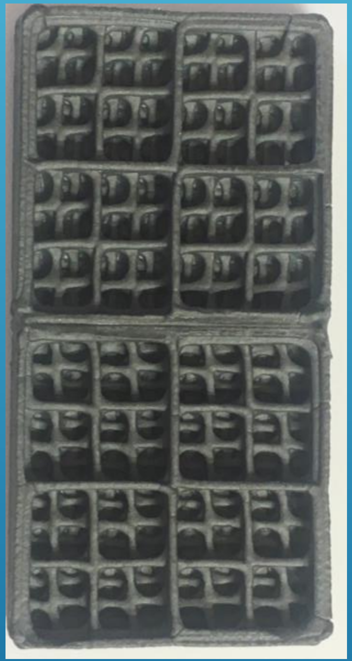
As-Printed and Cured. Feature sizes <0.8mm
Also demonstrated joining in “green-state”



Gradient Lattice Structure: 100% dense facesheet (bottom layer) to ~27% dense, 11 total layers. Reverse Pattern to Close-Out Backside for Highest First Mode and Dimensional Stability (like a SLMS)

PHASE I NASA MID-TERM RESULTS

- Individual “ribbons or layers” are 0.8-mm in diameter, feature sizes even smaller
- **Green-body machining demonstrated at Coastline Optics. Flat and parallel surfaces, knife edges 0.0001”**
- Bake-Out Shrinkage: x, y (optical surface) = 0.60 – 0.62 mm (3%); z = 0.13 mm (1.8 %); Mass lost = 3 %
- **Conversion to fully dense Reaction Bonded Silicon Carbide (3RB-SiC), Joining Demonstrated**
- **Can Additively Manufacture Complex Structures from Individual Components**
- Process will allow repairing of items that could possibly crack

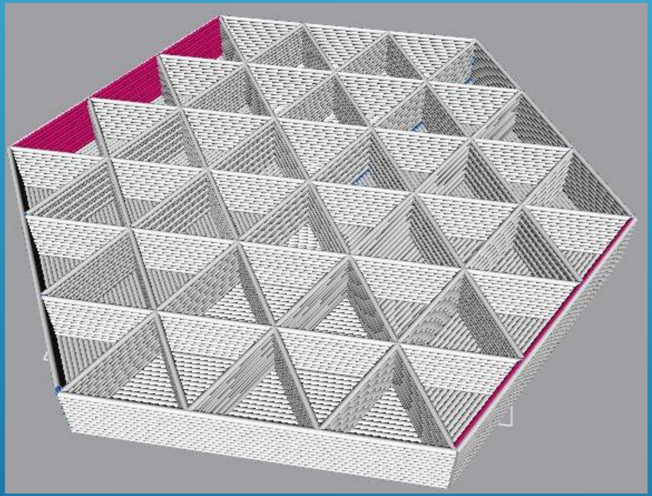


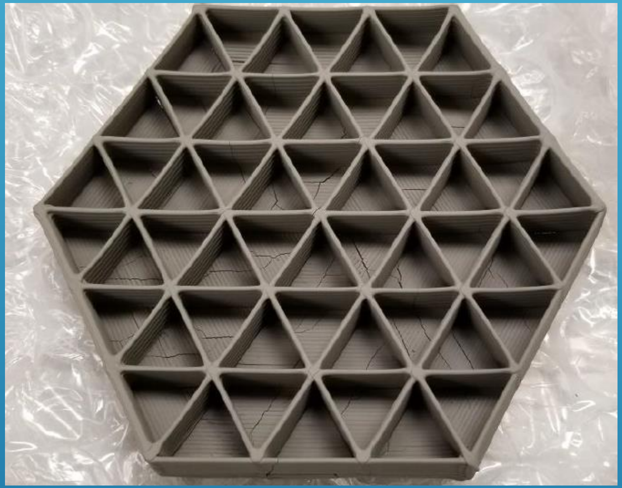
IR&D RESULTS: PRECISION LAPPING, JOINING & CERAMIZATION

- **Cured, Baked and Siliconized Part with NO prior Green-body Machining**
- **Successful Grinding of Reaction Bonded SiC**

IR&D RESULTS: CERAMIC GRINDING

- Printed 150mm Hexes with Isogrid. Why? Because Optics Folks Recognize the Pattern
- Guess What? Prints-Through During Curing Step (cracks, warp, delam)
- Potentially lots of ways to fix, but why?
- Isogrid Won’t Give the SLMS-style Performance Behavior NASA Requires





PROVEN AGAIN > GRIDS PRINT-THROUGH

- 60mm Square x 8.8mm w/Gradient Lattice
  - Equivalent to 32 ppi foam
  - Provides SLMS-Like Performance
  - High Specific Stiffness
  - Many Conduction Paths w/Facesheet
  - Square Arrays Easy for DMs to Map

- 30 min material prep, 20 minutes to print
  - *One Small Machine* Can Print $1.2m^2$/day
  - < 1-year to Print a 20m Aperture
  - *Large Machine 2-months?*

- Several Patent Pending Ways to Ceramize
- HUGELY Disruptive for the Optics Industry

BETTER BUILDING BLOCK FOR DIMENSIONAL STABILITY, SPECIFIC STIFFNESS AND/OR ACTIVE COOLING

- (as of 11/06/17) Phase I Ceramization In-Process at UH → 100% RoboSiC
  - 3rd Methodology to go with 3RB-SiC

- Phase II MATERIAL and PROCESS ENGINEERING:
  - Improve and Optimize Chemistry & Composition
  - Tailor Process for Large Prototype Machine
  - Combined 3D & Additive Manufacturing Approach for Large Structures

- Other Plans in Technology Roadmap:
  - Polish 3RB-SiC and RoboSiC at Coastline Optics
  - ***More Patent Pending Disruptive Technology Demos***

NEXT STEPS

- **Successful track record pioneering new materials & processes**
- **GT has GREAT technology partners**
- **IP Secured with Provisional Patent Filings**
- ***Tremendous Growth Potential Based Upon Optics and Other Identified Product Verticals and Markets***
- ***GT is actively seeking Growth Equity Partner and Capital***

SUMMARY