UT-CEM
Industrial Advisory Panel
November 14, 2017

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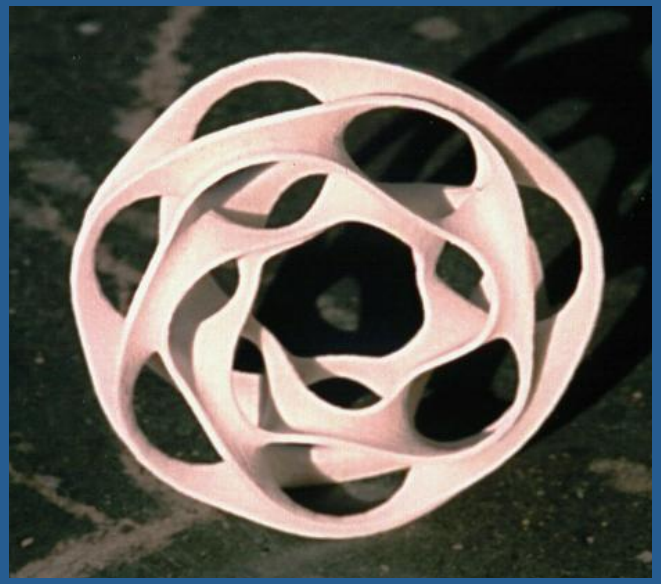
Advanced Manufacturing & Design Center
University of Texas at Austin

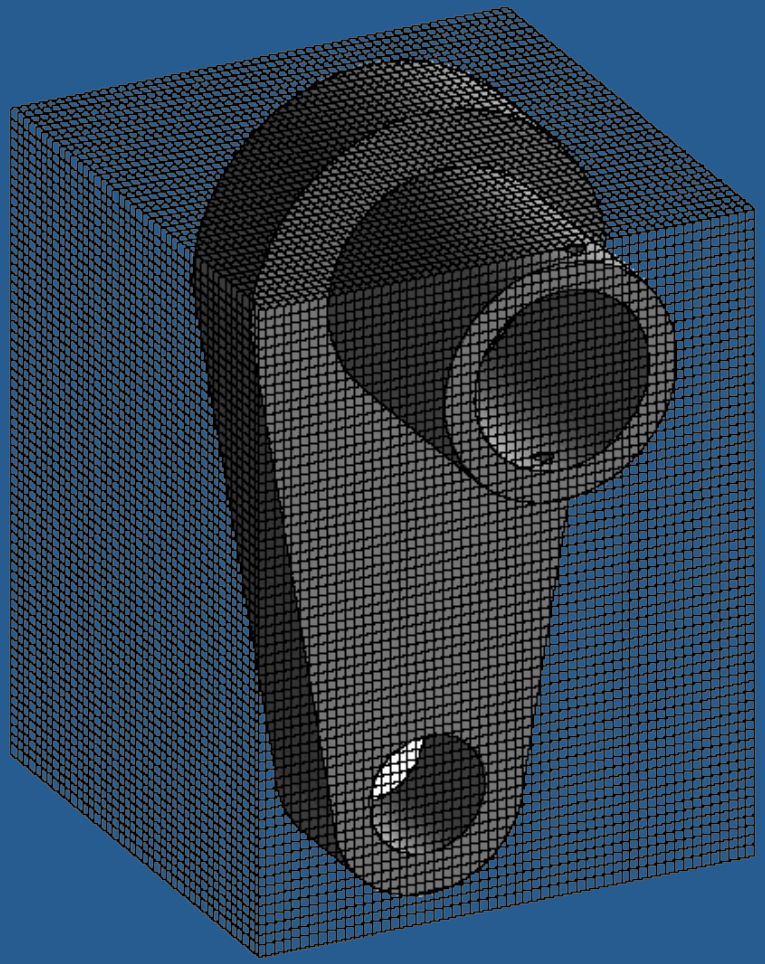
Solid Freeform Fabrication

Fabrication of complex freeform solid objects directly from a computer model of an object without part-specific tooling or human intervention.

Art to Part



Voxel Manufacturing - 1985



Layered Manufacturing, Additive Manufacturing

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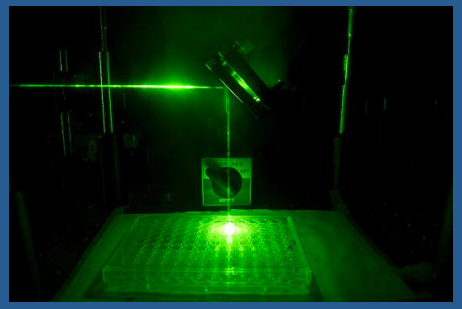
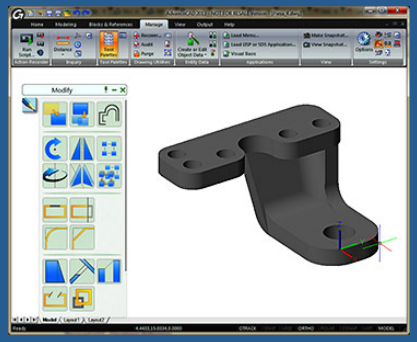
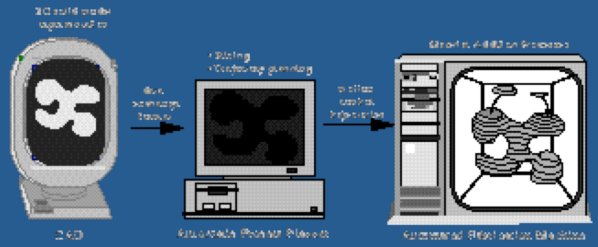
Three critical innovations in the 1980's



Economic Lasers: power & information



Solid Modeling: 3D geometry information



The PC: Information processing

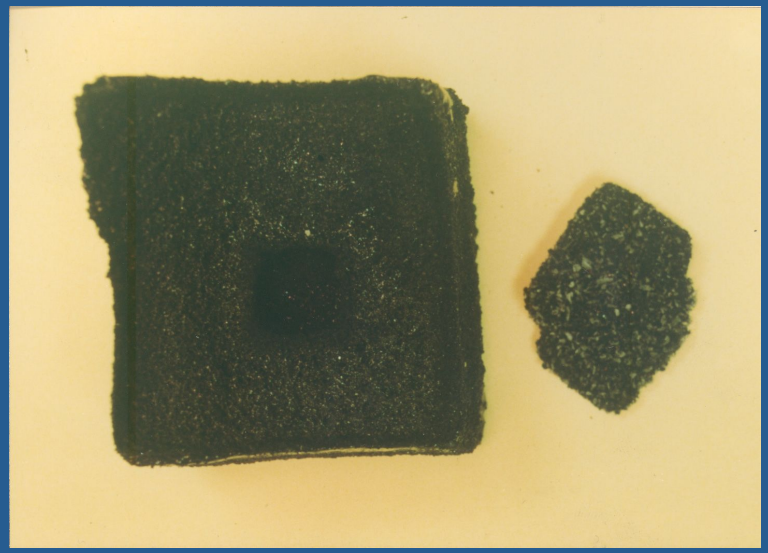
Selective Laser Sintering (SLS)

Technology: *Laser fused powders*

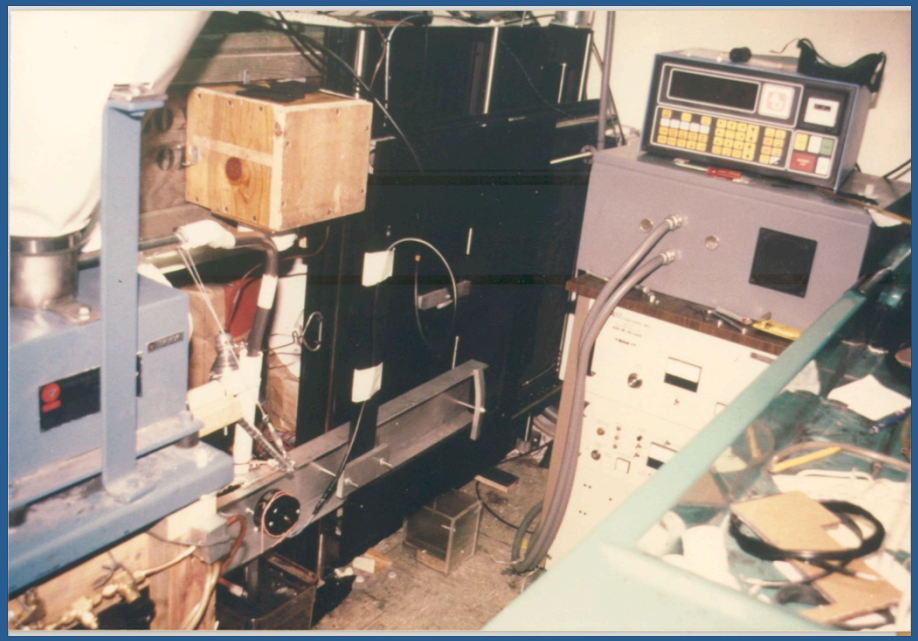
Introduced: *1992*

Major Vendor: *DTM*

Early (1987) SLS



First Parts



First Machine

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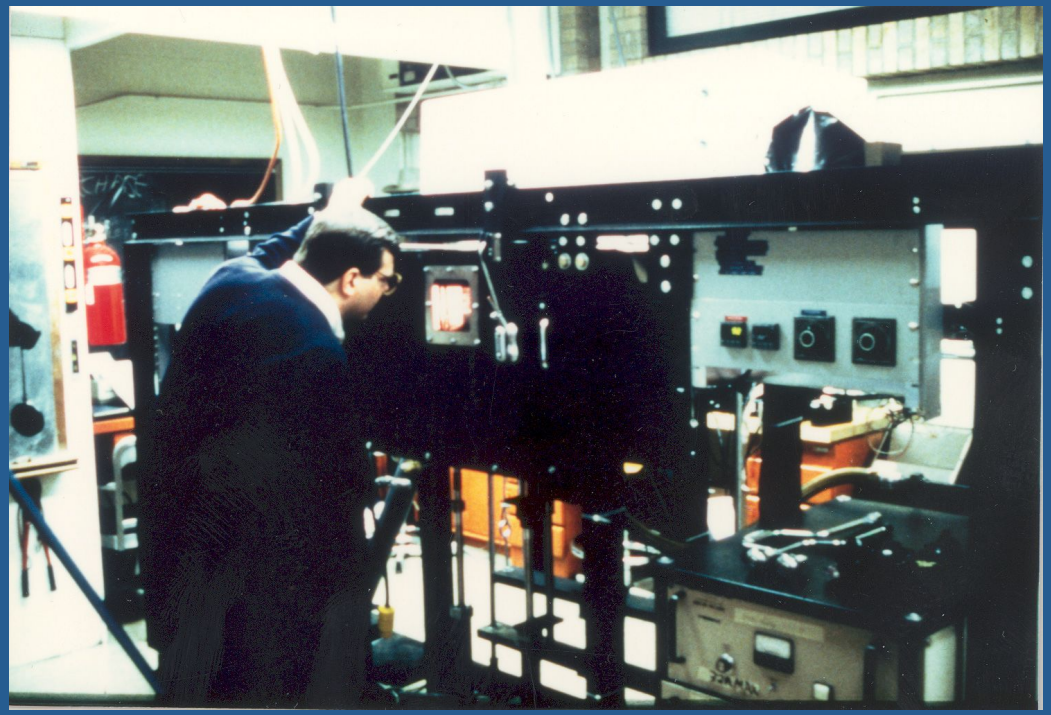
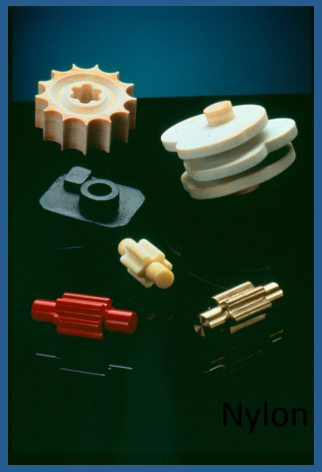
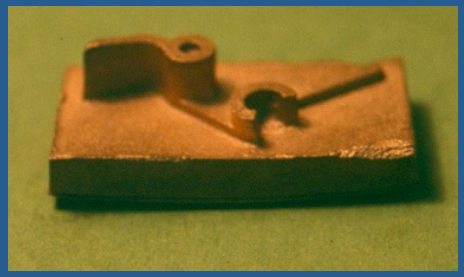
Bambi 1989 (2nd SLS Machine)



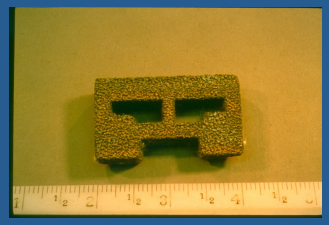
Bambi Parts



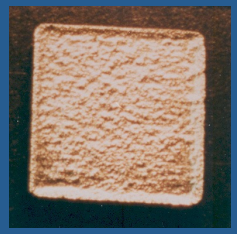
Nylon



Copper



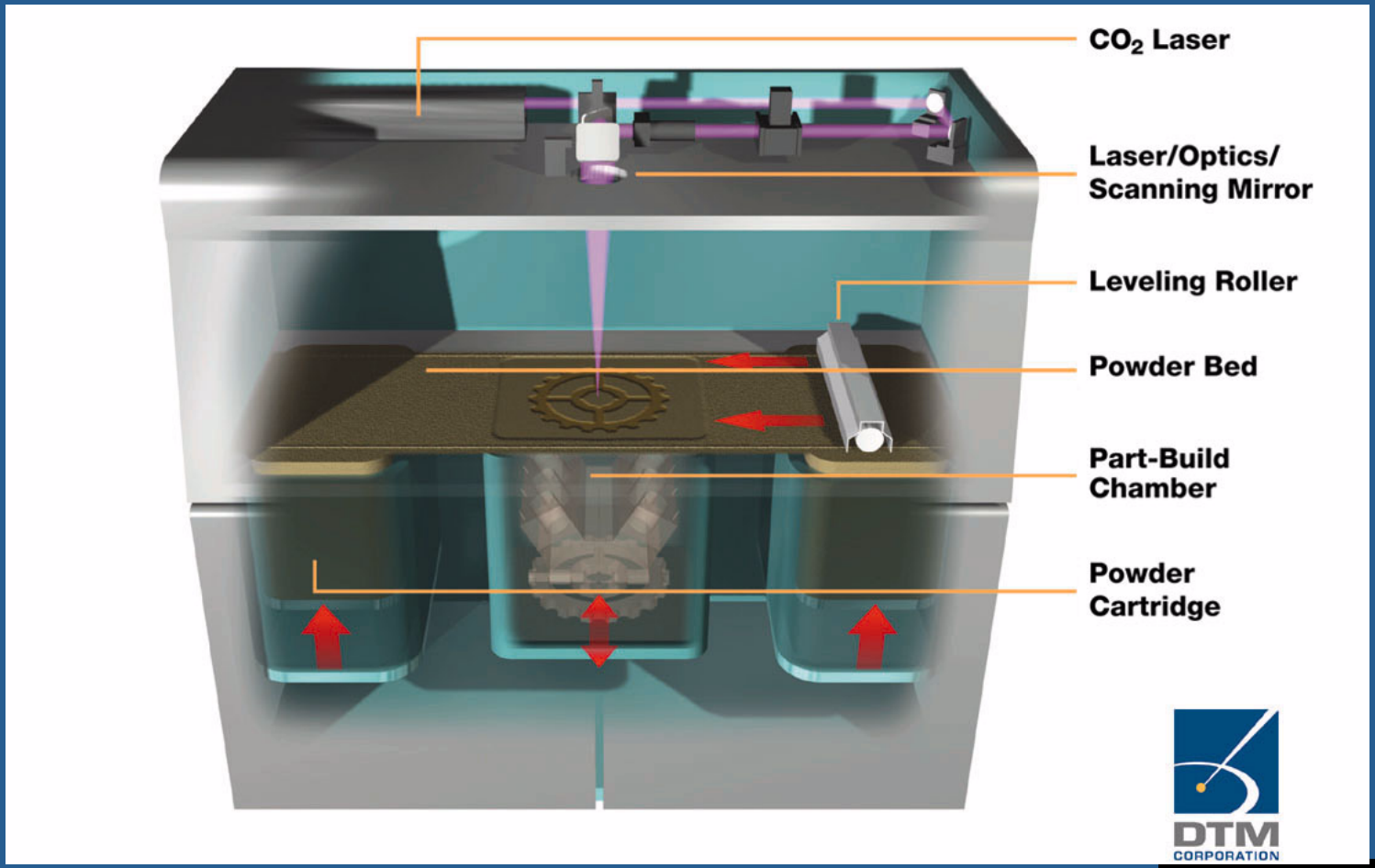
Bronze Nickel



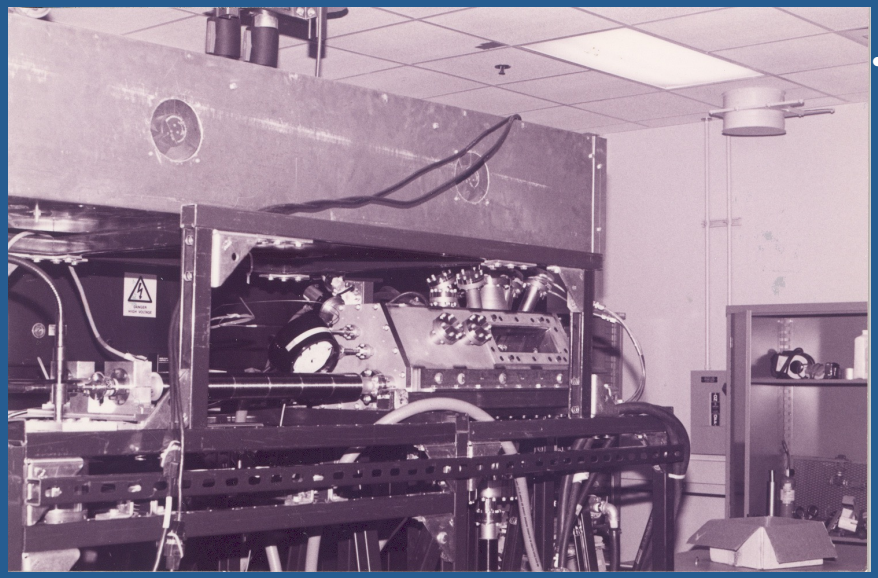
Stainless

Hydroxyapatite

DTM Corporation (1992)



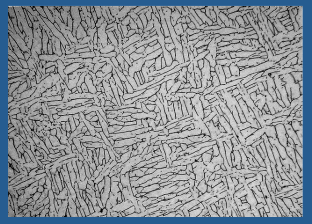
High Temperature SLS Workstation @ UT



- 1998 – Mil Spec Titanium part built with experimental SLS system with thermal control
  - Feed heater
  - Part heater
  - Vacuum capability
  - Powder O_2 quality control
  - Biasing temperature ~ 700°C
  - 1KW CO_2 laser
  - No support Structures

Super Alloys & Titanium

Ti64



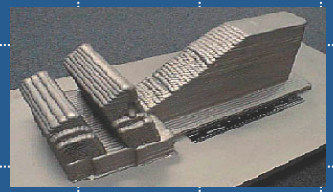
SFF Markets

Patterns

Manufacturing

Prototypes

3D Printing – Concept Models



Machining Forms

Accuracy

Strength

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Barriers to Additive Manufacturing

- Surface finish
- Production speed
- Cost
  - Machines
  - Materials
- **Variation from part to part**
  - **Inadequate process control**
- Materials availability

Short Runs are Important for SFF

From: Anderson, C., Wired Magazine

Small Lot Process Control

- Small lots are often high value. How to make yield 100%?
- Large volume statistics are not available.

Estimation Process

- Development of physical model
- Model Order Reduction if required for real time
- Measurement specification
- Uncertainty quantification
- Program for parallel computation if nonlinear

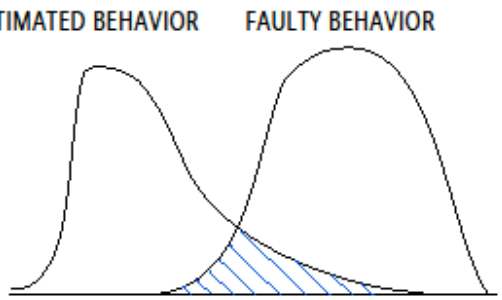
CeMs GPU Compiler

There are now very inexpensive parallel computers developed for the gaming industry – Graphic Processing Unit (GPU)

Compiler was developed for GPU (CUDA) NVIDIA GeForce GTX Titan, 12 streaming multiprocessors with 192 scalar processors, allows massive parallelization. Converts MATLAB code to CUDA.

1 million particles could be computed in real time.

• Cyber-Enabled Manufacturing Systems for SLS



SUBTLE CHANGES CAN BE USED TO ACCURATELY DETECT AN UPSET

Accurate nonlinear non-Gaussian estimation.

Cyber-physical systems (CPS) enable real-time operation.

Bayesian framework can be used for uncertainty quantification.

Development of the monitoring system can be automated.

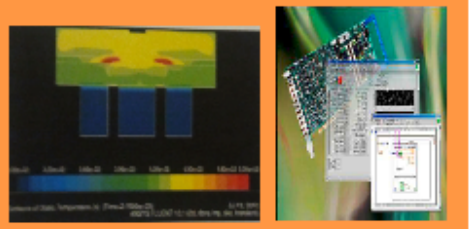
MAIN IDEA

optimal combination of information coming from sensors and that coming from a high-fidelity physics-based model running online

REAL-TIME MONITOR AND CONTROLLER

DIRECT METAL SLS MACHINE

MONTE CARLO METHODS FOR NONLINEAR NON-GAUSSIAN ESTIMATION



HIGH-FIDELITY COMPUTATIONAL MODEL

IR TEMPERATURE SENSORS

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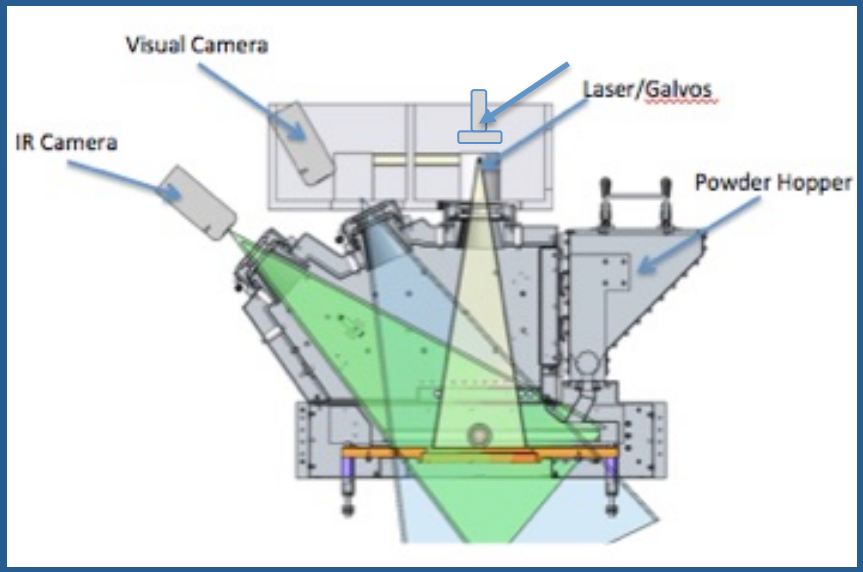
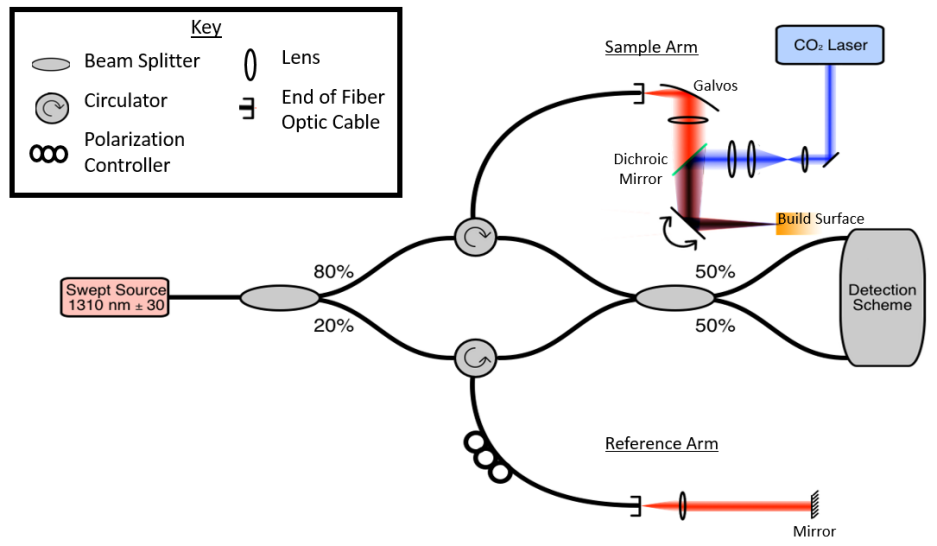
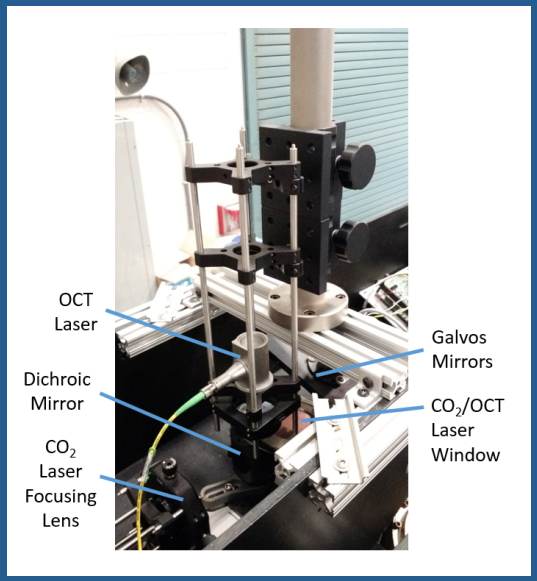
Experimental System for Process Control Studies

LAMPS Machine (AFRL)



Bore Sight OCT in LAMPS Machine





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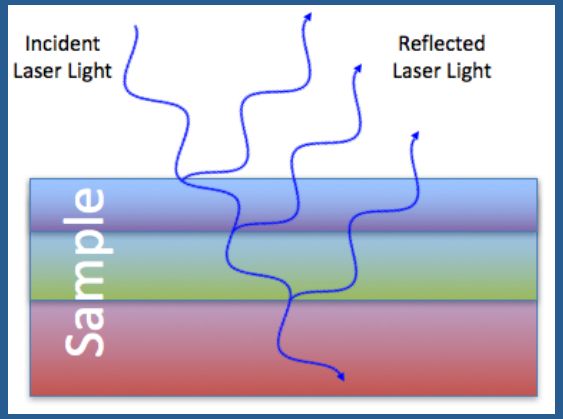
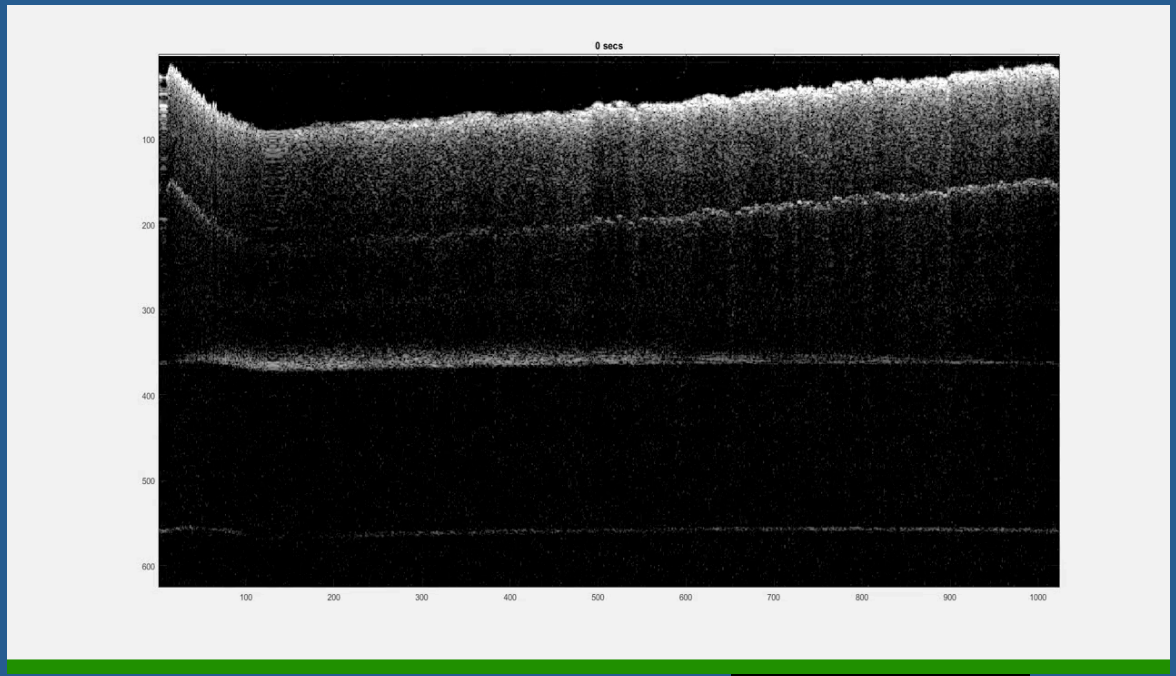
Flaw Detection

Weakest direction is typically ”Z” axis: poor layer to layer bonding

Exploring Optical Coherence Tomography to characterize subsurface conditions

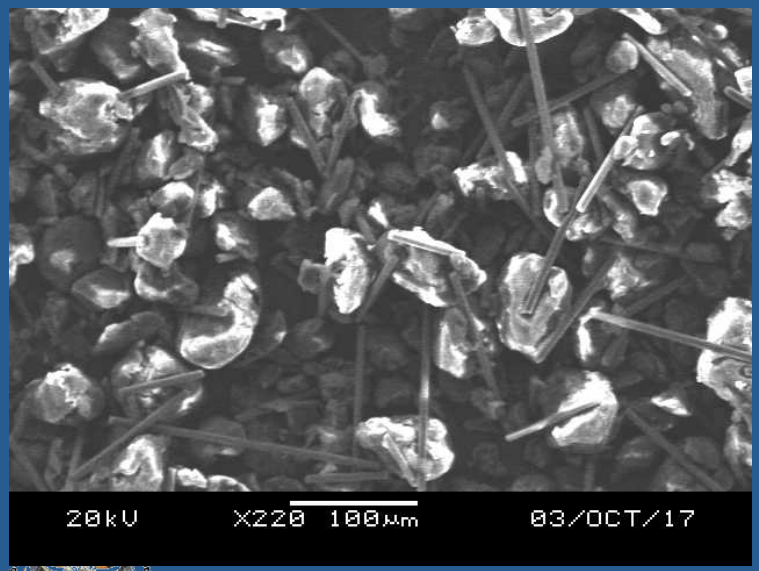


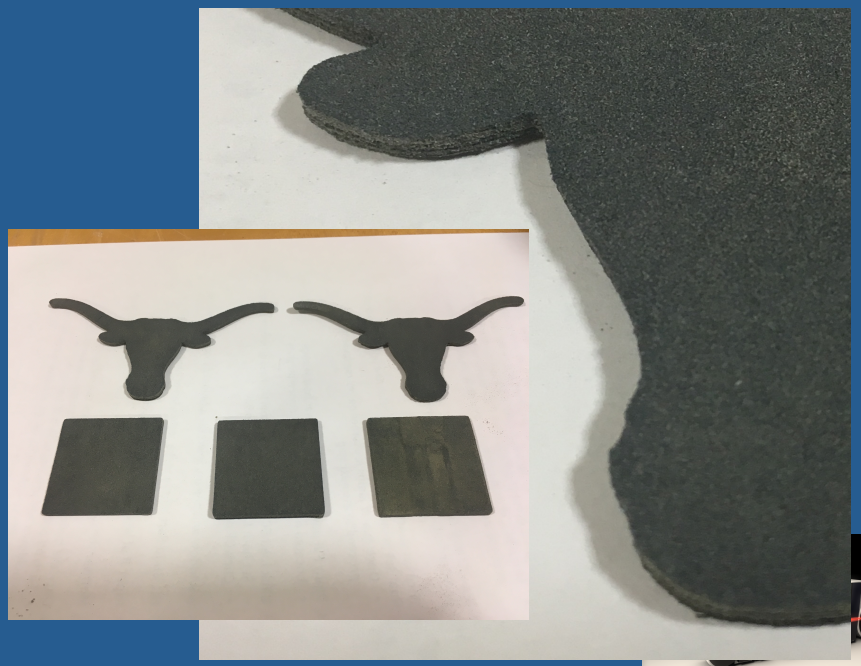
OCT Basics



Advanced Polymeric Materials

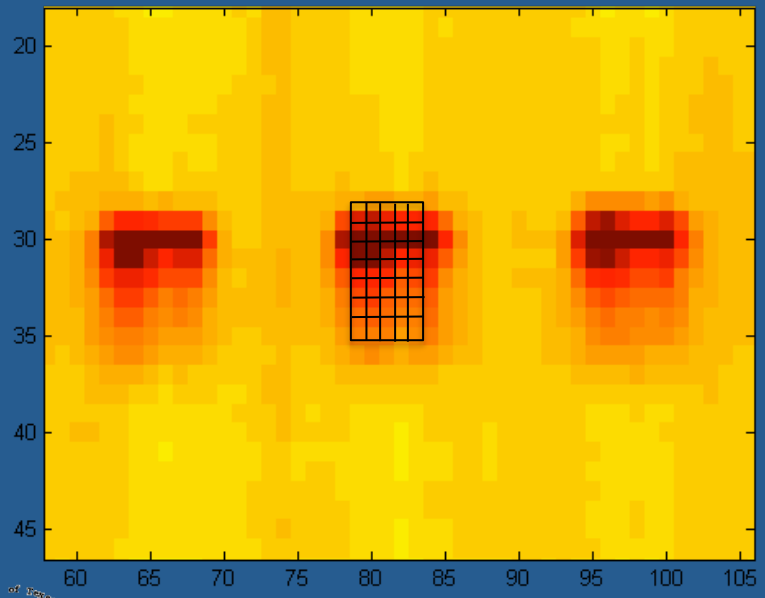
- Successfully built with 350 C melt PEEK
- Developing build process parameters for optimized post build performance
- Other polymer materials designed for SLS to be examined

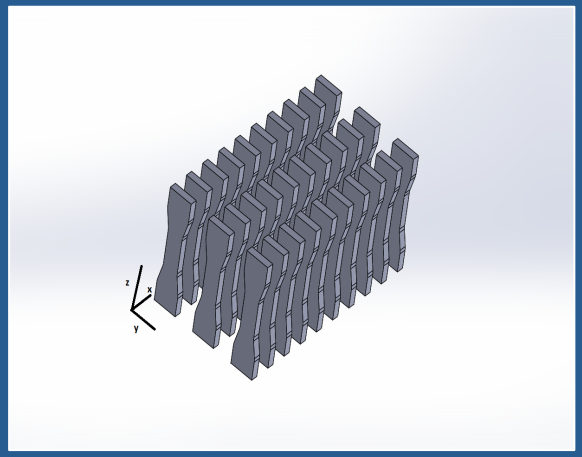




Temperature – Strength Study

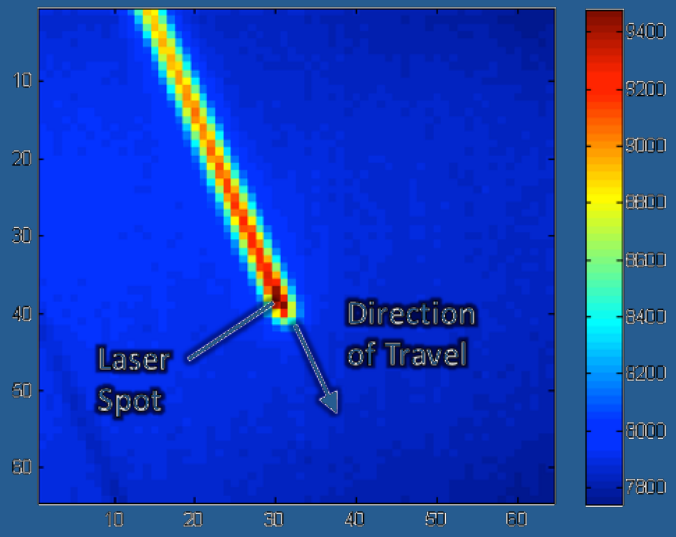
- Four Temperatures
  - Average Temperature across all layers
  - Pre-Sintering Temperature
  - Post-Sintering Temperature
  - Local-minimum Post-Sintering Temperature





In-Situ Laser Power Control

- High-speed mid-wave IR camera bore sighted with laser to share field of view
- Measuring initial powder temperature allows for calculation of correct laser power
- Estimation & control can be done in real time



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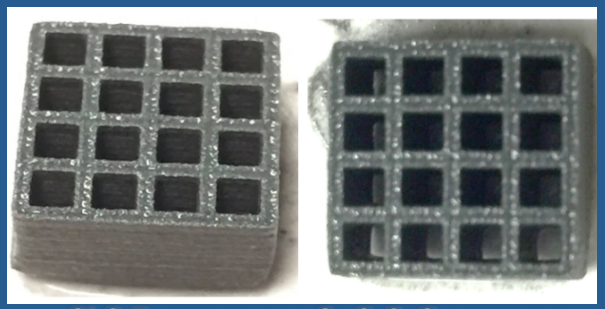
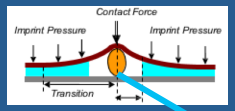
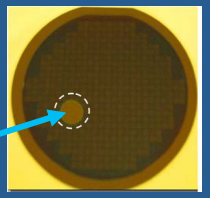
Micro/Nano AM with Ceramics



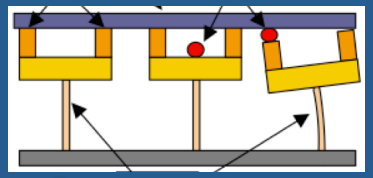
SLS PARTS FROM SI-SIC-C MIXTURE

Application: High Temp Compliant Pin Chuck for Wafer Processing

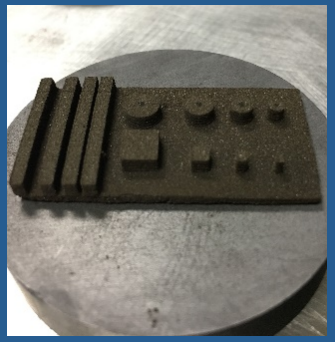




SUB 100NM CONTAMINANT REDUCES WAFER YIELD



COMPLIANT PIN CHUCK KEEPS WAFER FLAT



SLS "GREEN PARTS" FROM PHENOLIC + SIC

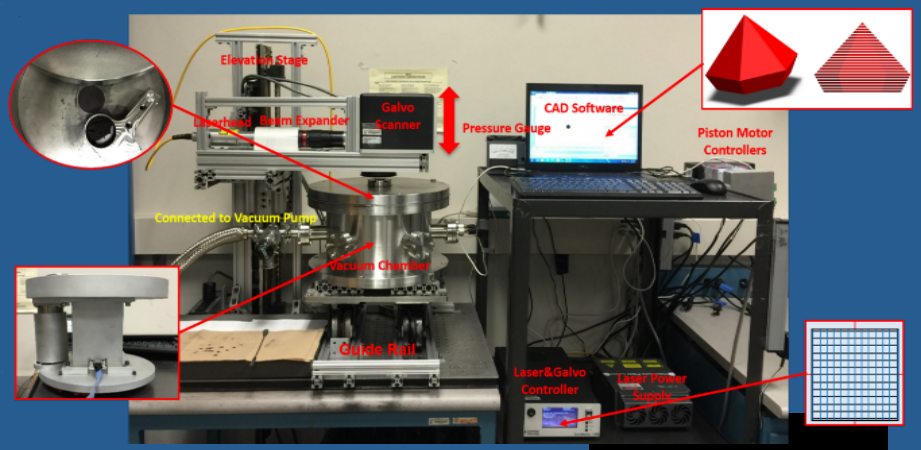


Fig. 4. Assembly of the NASCENT Center micro-SLS system.

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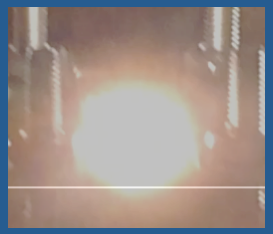
Flash Sintering AM

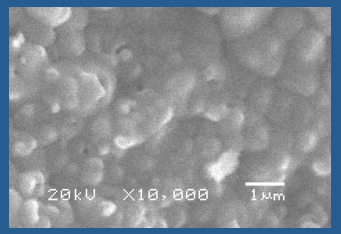
- Flash sintering uses an electric field to reduce furnace sintering times for ceramics from an hour to a few seconds.
- We have demonstrated flash sintering of alumina and zirconia ceramics during selective laser sintering.
- This process has potential to enable direct sintering of ceramics (no binder).

During SLS

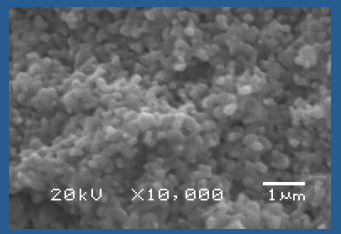
Microstructure

Laser sintering YSZ, with field

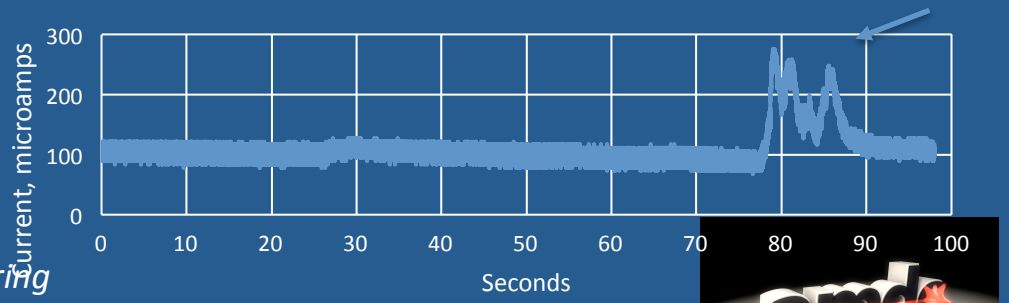




Laser sintering YSZ, no field



Current Spike During Laser Sintering, Yttria Stabilized Zirconia



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ARL South

- Manufacturing and Materials
- Cooperative Agreement
- In Start up

Conclusion

- Additive Manufacturing is an exciting and emerging field, but there is much yet to do to reach its potential.
- We look forward to working on mutually beneficial projects within CEM.