2PP Printing of 3D Deuterated Plastic Lattices: Challenges and Optimization

M. Do, A. Haid, T. Nunn, F. Elsner
General Atomics, P.O. Box 85608, San Diego, California 92186

GENERAL ATOMICS

TARGET OVERVIEW

General Atomics has developed materials and processes which enable 2PP printing of highly deuterated structures with minimal shrinkage and good mechanical properties for many application within Inertial Confinement Fusion. In Bosque campaign, Bosque capsules feature 3D printed deuterated plastic lattices filled with tritium and other gases, allowing for the manipulation of thermalization levels and mixing between reactants.

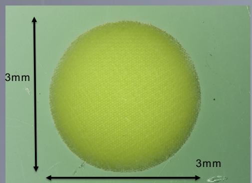


Image 1: Hemispherical Bosque Target Production.

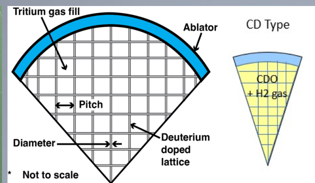


Image 3: Application of Bosque samples to study Thermonuclear Reaction Rates from Incomplete Mixing.

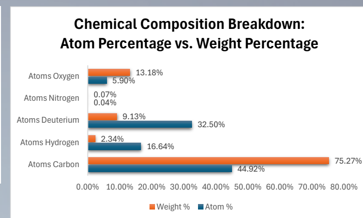


Image 5: Chemical Composition Analysis - Atomic vs Weight Percentages


Image 7: Second Generation Laser Lab Conducts Bosque Target Fabrication.

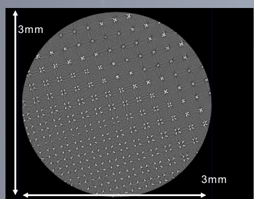


Image 2: 3D Tomography of Bosque Sample Presenting Simple Cubic Lattice Structure.

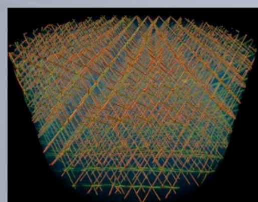


Image 4: 3D Tomography of Targeted CH Simple Cubic Lattice Structure for the Bosque Campaign.

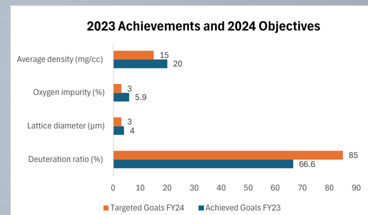


Image 6: Comparison of 2023 Achievements with 2024 Objectives

Purpose:

- To create a printable, highly 66% deuterated acrylate resin with low oxygen content with 5.9%.
- To consistently reproduce target samples with minimal shrinkage from 1-3% and low density from 16-25mg/cc.

TARGET FABRICATION CHALLENGES

- Precise control over geometric shape and density is difficult.
- Mismatch in refractive index.
- Bottom surface of hemispherical samples degrades at high temperatures or laser power.
- Custom-made deuterated resin:

1. Expensive, limiting research quantities.
2. Inconsistent properties, transitioning from liquid to solid.
3. Not transparent.

Tearing, Irregular Shapes and Structural Integrity Problems

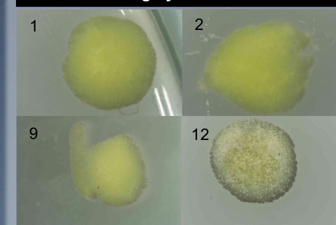


Image 8: Challenges in Fabricating Targets for Deuterated Materials.

Quality issues in printed samples:

- Sample 1: Tearing.
- Sample 2: Irregular shape.
- Sample 9: Diminished strength causing splitting.
- Sample 12: Incomplete printing at the bottom part.

3D Printing Challenge

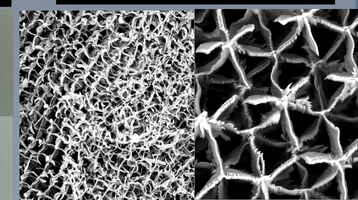


Image 9: Challenges in Fabricating Targets for Deuterated Materials.

- No structured strut pattern.
- Uneven lattice printing.

Solution:: Adjust heating, power settings, and overlapping layers of samples.

EXPERIMENTAL DATA

Stitching Effect

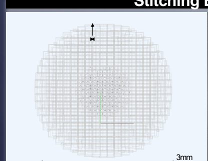


Image 10: The Square Field of View is Stitched together with 15 micron precision.

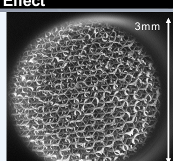


Image 11: SEM image of the Bosque Sample from the Top View.

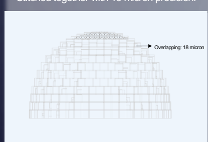
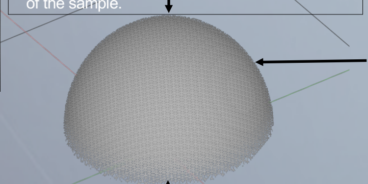


Image 12: The blocks of the Bosque samples are overlapped by 18 microns.

- Increasing the stitching size from 5 microns to 15 microns helps to reinforce the bonding between printed layers.

Laser Power of Top Surfaces vs Density

- Lower laser power at the top layers is required to prevent boiling effects from occurring on the top layer, with the aim of reducing the overall density of the sample.



Laser Power of Middle Surfaces vs Density

- Medium laser power at the middle layers is selected achieve sufficient light penetration into the material without excessive intensity, resulting in smoother surface finishes on the lattice structures produced.

Laser Power of Bottom Surfaces vs Density

- Higher laser power at the bottom surface is required to effectively address penetration challenges and improve the curing of the bottom layer.

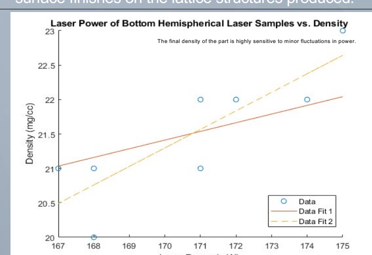


Image 14: Gradient Change in Laser Power at the Bottom Layers.

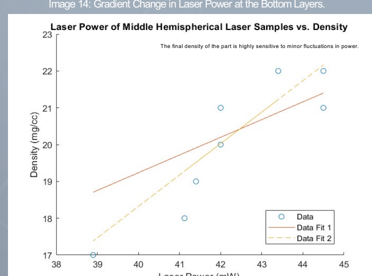


Image 15: Gradient Change in Laser Power at the Bottom Layers.

POST PROCESS CHALLENGES

Survivability

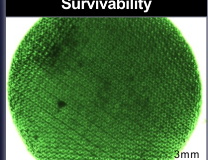


Image 13: Uniform Patterns and Strong Bonds between Lattice Structures Captured from the Microscope.

- Switching from 54°C to room temperature (~20 °C) reduces thermal contributions to optical distortions.
- At lower temperatures :

i. The material viscosity/flow remains more consistent.
ii. Thermal gradients are reduced.
iii. Residual stresses are minimized as cooling is more uniform.

- Rapidly immerse printed targets into 100% ethanol solvent can abruptly change their dimensions and cause significant damage to the part.

- Solution: Implement gradient exchange in an IPA solvent with UV curing before the post-processing step within Critical Point Drying to enhance the mechanical strength of low-density targets.

RESULTS

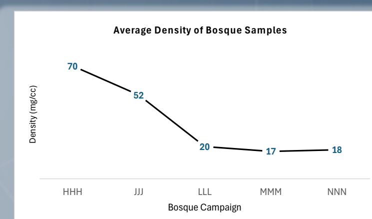


Image 16: Average density of Bosque samples across 5 campaigns.

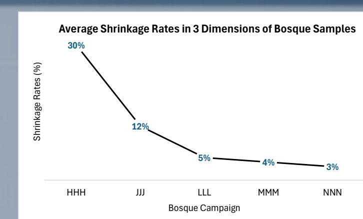


Image 17: Average Shrinkage Rates of Bosque samples across 5 campaigns.

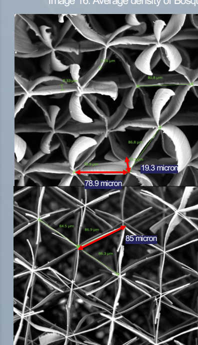


Image 18: Aspect Ratio of the Strut in the X-Y-Z Axis

- A consistent average density lower than 20 mg/cc has been achieved.
- Shrinkage rate is lower so that target fabrication is produced with consistent dimensions.
- After conducting extensive research post-processing stage, the fabricated targets show significantly improved survivability characteristics.

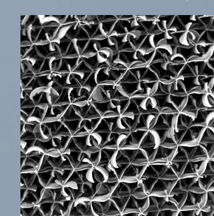


Image 19: SEM image of the Bosque sample

Future Plan

- **Install a Signal Delay Generator to control hardware and achieve an aspect ratio of 1:1.**
- **Increase the deuteration percentage to over 66.1% and reduce the oxygen percentage to below 5%.**
- **Modify the lattice geometry to investigate the extent of de-mixing.**

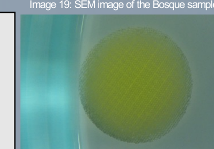


Image 20: Bosque sample

*This work performed under the auspices of the U.S. Department of Energy by General Atomics under Contract 89233119CNA000063

IFT\P2024-060