First demonstration of a layered direct-drive inertial confinement fusion target on the National Ignition Facility

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Previous design studies have proposed that direct laser ablation of liquid deuterium-tritium (DT) wetted foam (WF) inertial confinement fusion (ICF) targets[1] could achieve ignition on the National Ignition Facility (NIF) laser at Lawrence Livermore National Laboratory (LLNL)[2]. While the recent success of the laser indirect-drive (LID) approach to ICF has already demonstrated ignition[3], directly driven WF designs offer advantages such as higher laser-to-target coupling efficiency, reduced ablator mix, and lower in-flight aspect ratios. These features are expected to enhance robustness against target imperfections and drive nonuniformities, even within the polar-direct-drive (PDD) geometry of NIF. A multi-laboratory collaborative effort is currently investigating the feasibility of PDD-WF designs on NIF as next-generation igniting neutron sources for survivability experiments under NIF's National Security Applications Program[4]. The lower target mass provides a favorable environment for high-fluence neutron exposure experiments, while the liquid-layered approach significantly reduces fielding time compared to current β-layered ice designs. This effort includes the development of (i) novel two-photon-polymerization (2PP) additively manufactured (AM) capsules and (ii) cryogenic cooling via a conductive fill tube.

Experiment N250316-001 demonstrated the first layered direct-drive ICF target on the NIF laser. The target (see figure) consisted of a 3 mm diameter plastic capsule with a 15 μm thick shell and a 120 μm thick foam layer (70 mg/cc), both fabricated using 2PP. The shell and foam were printed concurrently, marking the fourth such target fielded on NIF. The foam layer was constructed from concentric icosphere surfaces composed of solid-density struts (~6 μm diameter × 30 μm length), designed to wick liquid deuterium throughout the structure, forming a WF layer surrounding a central vapor region that evolves into the hot spot. Cryogenic cooling was achieved via conduction through a 250 μm copper fill tube integrated into a flange printed with the capsule. The target was cooled to ~28 K, resulting in coexisting liquid and vapor deuterium phases with densities of ~150 mg/cc and ~6 mg/cc, respectively. The capsule was irradiated with an 850 kJ, 300 TW, 4 ns laser drive using a standard PDD pointing configuration[5]. Preliminary x-ray and nuclear performance data aligned with preshot HYDRA[6] radiation-hydrodynamics predictions, validating early modeling studies that suggested robust ignition could be achievable with such designs on the NIF platform.

We outline recent efforts focused on (i) AM capsule prototyping, fabrication, and proofing, (ii) experimental cryogenic target platform development and wetting tests, (iii) benchmarking experiments, and (iv) modeling studies to evaluate the risks and benefits of PDD-WF designs for ICF and inertial fusion energy (IFE) applications.

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