Hydrodynamic Stability of Direct-Drive Targets with High-Z Ablators

High-Z ablator (SiO₂)

First unstable ablation front

Second unstable ablation front

Thermal ablation front

σouter = 17 μm
σinner = 3 μm

CH ablator

σouter = 23 μm
σinner = 4 μm

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Summary

The use of high-Z ablators in direct-drive implosions is promising

- Cryogenic targets using ablators with a Z higher than plastic have higher two-plasmon–decay (TPD) intensity thresholds, decreasing the shell preheat caused by hot electrons.

- Hydrodynamic simulations using ablators ranging from carbon to silicon show similar Rayleigh–Taylor (RT) instability growth.

- A multilayer target, designed for sub-MJ shock ignition on the NIF, employs a graded-Z ablator and exhibits slightly improved stability in comparison with plastic-ablator targets.
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High-Z ablators are expected to reduce the hot-electron preheat caused by TPD instability.

The TPD growth rate* is

\[ \dot{\gamma} = \frac{L_{\mu m} I_{14}}{230 T_{keV}} - 1 - \frac{0.3 Z_{\text{eff}} L_{\mu m} \sqrt{I_{14}}}{230 T_{keV}^{5/2}} \]

**High-Z materials increase the intensity threshold of the TPD instability.**

High-Z ablator targets exhibit a double ablation front* and a classical interface

- Modulations of density grow exponentially with a linear growth rate** given by
  \[ \gamma_{RT} = \sqrt{\frac{A_T kg}{1 + A_T kL}} - 3 kV_a \]
  with \[ A_T = \frac{\rho_{max} - \rho_{min}}{\rho_{max} + \rho_{min}} \]

- The thermal front is almost fully stabilized by mass ablation
- The RT instability grows almost classically at the radiative front and the DT–SiO₂ interface

Hydrodynamic stability is studied for different high-Z ablators ranging from carbon to silicon.

Peak laser intensity: $9 \times 10^{14} \text{ W/cm}^2$

$V_{\text{imp}} = 390 \text{ km/s}$

$\alpha \sim 2.5$
Single-mode simulations show a slightly lower RT instability growth factor for high-Z ablators

- During the linear phase, the RT instability grows as $e^{\gamma t}$, where $\gamma$ is the growth rate and $\gamma t$ is the number of $e$ foldings.
High-Z ablators exhibit similar perturbations of the shell during the acceleration phase

Imprint simulations with $\ell < 200$ at $R = R_0/2$

- The plateau length $D_p$ is longer for higher-Z material
- High-$\ell$ modes develop at the radiative front
A high-Z ablating target has been designed for shock ignition on the NIF at sub-MJ energies.

Gain (1-D): 62

- $V_{\text{imp}}$ (km/s): 260
- Adiabat: 1.4
- IFAR$_{2/3}$: 23

Spike pulse: 230 kJ focused at ~0.4 $R_0$

Main drive: 630 kJ focused at ~$R_0$

Gain (1-D): 64

- $V_{\text{imp}}$ (km/s): 262
- Adiabat: 1.3
- IFAR$_{2/3}$: 28
The RT growth is mitigated by finite density gradients generated by multiple layers of doped plastic.

Using graded doping of plastic layers reduces the RT growth in a double-ablation-front structure.
The high-Z ablator design exhibits a slightly improved stability over the plastic ablator target.

Imprint simulations with $\ell < 200$ at the end of the acceleration phase.

**High-Z ablator (SiO$_2$)**
- First unstable ablation front
- Second unstable ablation front
- Thermal ablation front

*First unstable ablation front*
- $\sigma_{\text{outer}} = 17 \ \mu$m
- $\sigma_{\text{inner}} = 3 \ \mu$m

**CH ablator**
- First unstable ablation front
- Second unstable ablation front

*Second unstable ablation front*
- $\sigma_{\text{outer}} = 23 \ \mu$m
- $\sigma_{\text{inner}} = 4 \ \mu$m

**Density (g/cc)**
- Red: 8
- Orange: 5
- Green: 3
- Blue: 0
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