Modeling of Energy Transfer Between Spatially Incoherent Crossing Laser Beams

\[ \frac{n_e}{n_c} = 0.6 \]

\[ \langle I \rangle_{14} (\text{W/cm}^2) \]

\[ \text{Reflectivity (\%)} \]

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In direct-drive ICF plasmas, the nonlinear interaction between incoherent crossing laser beams leads to scattering, strongly influenced by the hot-spot structure.

Summary

- Nonlinear propagation of laser beams near their turning points provides a seed for scattering in the lower-density region.

- At moderate plasma densities, about $0.3 \, n_c$ to $0.6 \, n_c$, interaction between crossing laser beams can lead to a local reflectivity exceeding 20%.

- The hot-spot structure strongly influences
  - the direction of scattered light
  - the reflectivity scaling with intensity
1. Motivation from large-scale modeling of laser propagation and absorption

2. Nonlinear propagation of laser beams near their turning points

3. Nonlinear interaction between crossing laser beams at moderate plasma density about $0.3 \ n_c$ to $0.6 \ n_c$

4. Interaction between multiple laser beams incident at different angles
In large-scale hydrodynamic simulations, crossed-beam energy transfer is shown to significantly influence the laser absorption.

- Crossed-beam energy transfer reduces the energy of incoming center-beam rays and increases the energy of outgoing edge-beam rays.
- In direct-drive implosions there are multiple crossing beams.

Modeling of beam-to-beam coupling is based on the stimulated Brillouin scattering (SBS) gains

For direct-drive ICF plasmas the interaction between rays*:

\[
\frac{dI_1}{d\ell} = I_1 I_0 \frac{\omega_0^2}{2c^2 n_c} \text{Re} \left\{ \frac{n_e k_0^2 c_s^2}{2\nu_i \omega_s + i[(\omega_s + k_s v_0)^2 - k_s^2 c_s^2]} \times \frac{1}{2k_0 x} \right\}
\]

\[
\frac{dG_{SBS}}{d\ell} = I_0 = |E|^2 / 4\pi n_c T_e
\]

For indirect-drive plasmas**

– the propagation operators are applied to amplitudes of NIF beam centroids

\[ \vec{k}_1 \quad \vec{k}_0 \quad \vec{k}_s \]

Near the beam turning points, obliquely incident beams can seed scattering from other beams

In the region of moderate plasma density, about 0.3 $n_c$ to 0.6 $n_c$, the nonlinear propagation of crossing laser beams has been modeled.

**Two-dimensional non-paraxial model**

$L_n = 140 \ \mu m$

$T_e = 2 \ \text{keV}$

$f/6$ or $f/15$ DPP

Interaction in intense hot spots
The backscatter depends on the electromagnetic seed, which is due to opposing beams or to turning beams.

Scattering from a single DPP beam

\[ f/6 \quad \langle I \rangle_{14} = 7 \]

Seed: $10^{-4}$

Transmission $R = 17\%$

No seed

The threshold for the nonlinear backscattering driven by crossing laser beams has been found at moderate laser intensities.

- The intensities of the two driving beams are different by a factor of 10.

$$G_{SBS} = 0.24 \langle I \rangle_{14} \left( \frac{I_{\text{max}}}{I} \right)$$

The hot-spot structure determines the direction of scattered light.
In the case of incident beams of unequal intensity with smaller angular width, the backscattering for both beams is of the same order.

The reflectivity scaling is influenced by the hot-spot structure.
In the case of symmetrically incident laser beams close in intensity, the backscatter reflectivity is moderately higher.

\[
\langle I \rangle_1 = 7
\]

\[
R = 22\%
\]
The interaction of incoherent crossing laser beams with plasmas produces a broad spectrum of low-frequency density perturbations.

Laser beams can share density perturbations.
At moderate densities, the interaction between beams incident at different angles leads to a broad spectrum of backscattered light.
The interaction between multiple obliquely incident beams at moderate densities can increase the backscatter

\[ \langle I \rangle_{14} = 9 \]
In direct-drive ICF plasmas, the nonlinear interaction between incoherent crossing laser beams leads to scattering, strongly influenced by the hot-spot structure.

- Nonlinear propagation of laser beams near their turning points provides a seed for scattering in the lower-density region.

- At moderate plasma densities, about $0.3 n_c$ to $0.6 n_c$, interaction between crossing laser beams can lead to a local reflectivity exceeding 20%.

- The hot-spot structure strongly influences
  - the direction of scattered light
  - the reflectivity scaling with intensity

- For comparison with the ray-based model, the importance of hot spots for backscatter and reflectivity scaling in large-scale modeling is being studied.