Energy Transfer Between Crossing Laser Beams in the Plasmas of Direct-Drive ICF

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In direct-drive ICF plasmas, nonlinear interaction between crossing laser beams leads to significant scattering.

- At moderate plasma densities (0.3 to 0.6 critical density), interaction between incident laser beams and a counter-propagating seed can lead to a local reflectivity exceeding 20%.
- The direction of scattered light is determined by the structure of laser speckles.
- Interaction in intense speckles leads to a power scaling of reflectivity with intensity.
- Nonlinear propagation of laser beams near their turning points provides a seed for scattering in the lower-density region.
In large-scale hydrodynamic simulations, crossed-beam energy transfer is shown* to significantly influence the laser absorption

- For direct-drive ICF plasmas, the interaction between rays is

\[
\frac{dI_1}{d\ell} = I_1 I_0 \frac{\omega_0^2}{2c^2 n_c} \text{Re} \left[ \frac{n_e k_s^2 c_s^2}{2\nu i\omega_s + i[(\omega_s + k_s v_0)^2 - k_s^2 c_s^2]} \times \frac{1}{2k_{0x}} \right]
\]

- Crossed-beam energy transfer reduces the energy of incoming center-beam light and increases the energy of outgoing edge-beam light

I. V. Igumenshchev et al., YI3.00001
The nonlinear propagation of crossing laser beams has been modeled in the region of moderate plasma density, about $0.3 \, n_c$ to $0.6 \, n_c$

Two-dimensional non-paraxial model

$L_n = 140 \, \mu m$
$T_e = 2 \, keV$

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

Seed: $10^{-4}$
The backscatter depends on the electromagnetic seed, which is caused by opposing beams or turning beams.

Scattering from a single DPP beam*

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

The threshold for the 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.

\[ SBS_{14}^{\text{max}} = f \]

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

Interaction in intense hot spots
The reflectivity has a moderate dependence on the distribution of intensity between the driving laser beams.

The hot-spot structure determines the direction of scattered light.
The interaction of incoherent crossing laser beams with plasmas produces a broad spectrum of low-frequency density perturbations.

$L_n = 140 \, \mu m$
$T_e = 2 \, keV$

Laser beams can share density perturbations.
Nonlinear interaction in intense laser speckles determines the scaling of reflectivity with intensity

Reflectivity

\[ \frac{d\langle R \rangle}{dx} \sim U_m^3 e^{-U_m}, \]

where

\[ U_m \equiv \frac{I_m}{\langle I \rangle} \]

for the saturation \( R_{\text{sat}} \)

\[ R_{\text{sat}} = \varepsilon \cdot e^{G_{\text{SBS}} U_m} \]

\( \varepsilon \) – seed

The reflectivity scaling is influenced by the hot-spot structure.
At moderate plasma densities, the interaction between beams incident at different angles leads to a broad spectrum of backscattered light.
In direct-drive ICF plasmas, nonlinear interaction between crossing laser beams leads to significant scattering

- At moderate plasma densities (0.3 to 0.6 critical density), interaction between incident laser beams and a counter-propagating seed can lead to a local reflectivity exceeding 20%

- The direction of scattered light is determined by the structure of laser speckles

- Interaction in intense speckles leads to a power scaling of reflectivity with intensity

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