Scattering of Multiple Crossing Laser Beams in Direct-Drive Inertial Confinement Fusion (ICF) Plasmas

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Summary

For direct-drive ICF plasmas, scattered light is driven by crossing laser beams that generate common ion waves

- Multiple crossing beams can drive common ion waves and scatter off them, increasing the reflectivity.
- The laser speckle structure determines the angular distribution of scattered light and the scaling of reflectivity with intensity.
- For multiple beams incident at different angles, multiple common ion-wave gratings can increase the reflectivity.
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 nonparaxial model

\[ L_n = 140 \ \mu m \]
\[ T_e = 2 \text{ keV} \]

Seed: \( 10^{-4} \)

\[ \frac{n_e}{n_c} = 0.3 \]

\[ \frac{n_e}{n_c} = 0.6 \]
The reflectivity has a moderate dependence on the distribution of intensity between the driving laser beams.

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

\[ \frac{I_+}{I_+ + I_-} \]

Intensities of two driving beams differ by a factor of 10

At \( \langle I \rangle_{14} = 3.5 \) no reflectivity

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

Interaction in intense hot spots
The interaction of incoherent crossing laser beams with plasmas produces a broad spectrum of low-frequency density perturbations.

Laser beams can share density perturbations.

\[ \langle I \rangle_{14} = 8 \]

\[ L_n = 140 \, \mu m \]

\[ T_e = 2 \, \text{keV} \]

\[ f/6 \]

Caused by crossing beams

Caused by single beam

Common ion waves

Caused by backscattering of individual beam
Crossing laser beams can scatter off common ion waves driven by multiple beams

Backscattering of individual beams

\[ \overrightarrow{k}_0^{(1)} - \overrightarrow{k}_1^{(2)} - \overrightarrow{k}_1^{(1)} - \overrightarrow{k}_0^{(2)} \]

Scattering off common ion waves

\[ \overrightarrow{k}_0^{(1)} - \overrightarrow{k}_1^{(1)} - \overrightarrow{k}_a^{(2)} - \overrightarrow{k}_0^{(2)} \]

\[ \frac{dE_1^{(1)}}{d\varphi_1} = g[k_{la}^{(1)}][E_1^{(1)}E_0^{(2)*} + E_1^{(2)}E_0^{(1)*}]E_0^{(2)} + g[k_{la}^{(1)}]E_0^{(1)}E_1^{(1)} \]

\[ \frac{dE_1^{(2)}}{d\varphi_2} = g[k_{la}^{(1)}][E_1^{(1)}E_0^{(2)*} + E_1^{(2)}E_0^{(1)*}]E_0^{(1)} + g[k_{la}^{(2)}]E_0^{(2)}E_1^{(2)} \]

Scattering is possible in the direction opposite to the weaker beam.
Resonant conditions for common ion waves depend on the angle between driving laser beams.

\[
g[k_{ia}] = \frac{\omega_0^2}{16\pi n_e^2 T_e c^2} \times \frac{n_e k_{ia}^2 c_{ia}^2}{2\nu_i \omega_{ia} + i\left[\left(\omega_{ia} + k_{ia} v_0\right)^2 - k_{ia}^2 c_{ia}^2\right]} \times \frac{1}{2k_{0x}}
\]

The difference in the resonance width in \( g(k_{ia}^{(c)}) \) versus \( g(k_{ia}^{(1)}) \) and \( g(k_{ia}^{(2)}) \) is \( \sim (\sin \theta)^2 \) comparable to width caused by damping and inhomogeneity.
The 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 \( R_{\text{sat}}^* \)

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

\( \varepsilon \) – seed

Coupling via common grating is weaker for larger \( \theta \)

The interaction between beams incident at different angles can generate common ion waves.
The interaction between multiple obliquely incident beams at moderate densities increases the backscatter as the result of sharing multiple common ion waves.

Multiple common ion waves can be close to resonant.
Summary/Conclusions

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