Effects of Beam Incoherence and Colors on Cross-Beam Energy Transfer

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Summary

In direct-drive inertial confinement fusion (ICF) plasmas, the use of colors in incoherent laser beams can mitigate the cross-beam energy transfer (CBET)

- In dense plasmas (including beam-turning points) CBET is strongly influenced by common ion-wave gratings
- The use of frequency detuning (colors) in laser beams
  - reduces the role of common ion waves
  - increases the frequency broadening of scattered light
- Both of these effects can limit CBET
Outline

• CBET model in dense plasmas (including the turning points of laser beams)
• CBET driven by multiple incoherent laser beams generating common ion gratings
• Influence of beam frequency detuning (colors) on CBET
• CBET between beams with a large intensity contrast
Nonlinear propagation of laser beams with frequency detuning is modeled in dense plasmas

- Beams with wavelength detuning are used to limit beam-to-beam coupling
  - two-dimensional non-paraxial model near turning points
  - related to parameters from simulations of OMEGA experiments (flow velocity $\ll C_s$)

\[
T_e = 2 \text{ keV} \\
\Delta \lambda_0 = 0, \pm 1.8 \text{ Å} \\
\theta = \pm 15^\circ \\
f/6 \\
\langle I_{14} \rangle = 8
\]
The laser–plasma interaction model includes backward and forward stimulated Brillouin scattering (SBS), beam self-focusing, field swelling, and absorption.

- Beam-to-beam coupling can be described by backward SBS gains

\[
\frac{dG_{\text{SBS}}}{d\vec{\ell}} = \frac{\omega_0^2}{2c^2 n_c} \Re \left\{ \frac{n_e k_s c_s^2}{2 \omega_s + \nu_i (\omega_s + k_s v_0)^2 - k_s^2 c_s^2} \times \frac{1}{2k_{0x}} \right\},
\]

\[
I_0 = \frac{|E|^2}{4\pi n_c T_e}
\]

\[
\langle I_{14} \rangle = 8
\]

Angular light spectrum

The angular width of scattered light is increased
Crossing laser beams can backscatter off common ion waves

\[ k_0 = \frac{\omega_0}{c} \sqrt{1 - \frac{n_B}{n_c}} \]

IAW: ion-acoustic wave
Crossing multiple laser beams in dense plasmas generates multiple common ion waves.

The angular width of scattered light is increased

\[ \langle I_{14} \rangle = 8 \]

\[ \theta = \pm 15^\circ, \pm 30^\circ \]

\[ \Delta \lambda = 0 \]
Irradiation by multiple beams leads to broad spectra of density perturbations

\[ k_0 = \frac{\omega_0}{c} \sqrt{1 - \frac{n_B}{n_c}} \]

\[ \langle I_{14} \rangle = 8 \]
CBET is significantly reduced when frequency detuning (colors) is applied to crossing laser beams.

Four laser beams

\[ \theta = \pm 15^\circ, \pm 30^\circ \]
\[ \langle I_{14} \rangle = 8 \]
\[ I_{\text{outer}}/I_{\text{inner}} = 1 \]
The frequency spectra of scattered light from multiple crossing beams are strongly modified by the beam frequency detuning.

\[
\Delta \lambda = 0
\]

\[
\Delta \lambda = \pm 1.8 \text{ Å}
\]

\[
\langle I_{14} \rangle = 8
\]
The influence of frequency detuning (colors) on CBET in crossing laser beams includes the reduction of common ion waves.

Four beams

\[ \langle I_{14} \rangle = 8 \]

\[ \Delta \lambda = \pm 1.8 \text{ Å} \]

Density perturbation spectrum

- Beating of beams
- Backscatter
- Common wave

\[ k_x/k_0 = \frac{\omega_0}{c} \sqrt{1 - \frac{n_B}{n_c}} \]
Wavelength detuning in incoherent laser beams significantly reduces the intensity of backscattered light.
CBET driven by incoherent laser beams with a large intensity contrast can increase the backscatter of weaker beams

\( \langle I_{14} \rangle = 8 \)

\( I_{\text{outer}}/I_{\text{inner}} = 0.25 \)

\( \Delta \lambda = 0 \)

\( R = 0.33 \)

\( \langle I_0/I_i \rangle = 0.58 \)

\( \Delta \lambda = \pm 1.8 \, \text{Å} \)

\( R = 0.15 \)

\( \langle I_0/I_i \rangle = 0.61 \)
Summary/Conclusions

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