Two-Plasmon-Decay Instability Driven by Incoherent Laser Irradiation

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Summary

The onset of TPD instability and preheat in direct-drive plasmas is strongly influenced by laser-beam incoherence

- The TPD driven by incoherent laser beams has a regime where the growth rate is determined by the overlapped laser-beam intensity.
- For parameters of laser–plasma interaction in OMEGA plasmas, the threshold of TPD depends on the interplay between
  - plasma inhomogeneity
  - wave damping
  - resonance detuning due to beam incoherence
- When the density scale length is large enough, the low-frequency density perturbations can reduce the TPD growth.
In OMEGA experiments, the hard x-ray production depends on the overlapped intensity of multiple incoherent laser beams.
The growth rate of the TPD instability can be proportional to the average laser intensity.

- Equation for the growth rate $\gamma$ (in random phase approximation):

$$
\frac{2(\gamma + \gamma_e)}{\omega p_0} = -\text{Im} \int \frac{d\vec{k}_0}{k_0 \Delta \theta} \frac{\langle |v_0|^2 \rangle F(\vec{k}_0, \vec{k})}{2i(\gamma + \gamma_e)\omega p_0} - 3v_T^2 \left( (\vec{k}_0 - \vec{k})^2 - (\vec{k}_0C - \vec{k})^2 \right)
$$

where $F(\vec{k}_0, \vec{k}) = \frac{(k_0^2 - 2\vec{k}_0 \vec{k})^2}{4[ (\vec{k}_0 - \vec{k})^2 k^2]}$ and $\gamma_e$ is the damping coefficient.

- Large resonance width: $(\gamma + \gamma_e) \ll \Delta \omega$

$$
\gamma + \gamma_e = \frac{\pi}{4} \frac{\langle |v_0|^2 \rangle F(\vec{k}_0C, \vec{k})}{\Delta \omega}
$$

$\Delta \omega = 3k_\Vert k_0 \lambda^2 D_e \sin \theta_c |\Delta \theta \omega p_0$
The increase of the angular width of an incoherent laser beam leads to the decrease of TPD growth rate and to the increase of the threshold.

\[ \gamma_e/\omega_p = 10^{-3} \]

\[ (\gamma + \gamma_e)/\omega_p \approx \sqrt{\langle I \rangle / I_0} \text{ at } \Delta \omega = 0 \]

Resonance width \[ \Delta \omega/\omega_p = 3k_k_0 F_0^2 |\sin \theta_c| \Delta \theta \]
Thresholds of TPD in OMEGA plasmas are influenced by the density inhomogeneity scale

- Different studies* have shown that for TPD in inhomogeneous plasmas the absolute growth rate

\[
\left(\frac{\gamma}{\omega p_0}\right)_{\text{inhom}} = \left(\frac{\gamma}{\omega p_0}\right)_{\text{hom}} - \Delta_{\text{inhom}} - \left(\frac{\gamma_e}{\omega p_0}\right)
\]

\[\Delta_{\text{inhom}} \sim \frac{1}{k_0 L_N}\]

- For OMEGA plasmas the density scale length near quarter-critical density

\[L_N = (150-400) \mu m\]

- Low-frequency density perturbations can increase the effective damping

\[\gamma_e \sim \sqrt{(\delta N)^2} \sim \frac{1}{\gamma_{ia}}\]

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For parameters of OMEGA plasmas, the TPD instability threshold is influenced by the interplay of several parameters:

- Homogeneous three-wave growth rate
  \[ \gamma^0 = \frac{k_0 |V_0|}{\omega_{p0}} = 8.2 \times 10^{-3} \sqrt{I_{15}} \]

- Detuning due to beam incoherence
  \[ \frac{\Delta \omega}{\omega_{p0}} = 2 \times 10^{-3} \left( \frac{T_e}{2 \text{ keV}} \right) \left( \frac{\Delta \theta}{0.2} \right) \sin \theta_c \]

- Plasma-wave damping
  \[ \left( \frac{\gamma_e}{\omega_{p0}} \right)_{\text{coll}} = 0.5 \times 10^{-3} \left( \frac{Z}{5.3} \right) \left( \frac{T_e}{2 \text{ keV}} \right)^{3/2} \]

- Detuning due to inhomogeneity
  \[ \frac{1}{k_0 L} = 4.2 \times 10^{-4} \left( \frac{L}{150 \mu m} \right) \]
In OMEGA experiments, the hard x-ray production depends on the overlapped intensity of multiple incoherent laser beams.

Experimental HXR

- Laser intensity (W/cm²) \( \times 10^{14} \)
- Emission (pC)

- Thin cryo ablator
- Thick cryo ablator
- Si-doped CH
- CH, CD
- Si-doped CH Threshold

TC8036a
Low-frequency perturbations in electron density are produced by the interaction of incoherent laser beams with plasmas.

\[ \langle I \rangle = 9 \times 10^{14} \text{ W/cm}^2, \quad T_e = 2 \text{ keV}, \quad n_e = \frac{n_c}{4} \]

\[ \left( \frac{n_e}{n_0} - 1 \right) \sim \frac{I}{\langle I \rangle} \]
The low-frequency perturbations in the electron density can detune the TPD resonance and reduce the TPD growth.

\[ \langle I \rangle = 9 \times 10^{14} \text{ W/cm}^2, \quad \gamma_e/\omega_{p0} = 10^{-3} \]
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