Modeling of Two-Plasmon-Decay Instability Under Incoherent Laser Irradiation



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Summary

In OMEGA plasmas the onset of TPD instability, and consequently preheat, is strongly influenced by laser beam incoherence

• The TPD, driven by incoherent laser beams, has a regime where the growth rate is proportional to overlapped laser-beam intensity.

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- For parameters of laser-plasma interaction in OMEGA plasmas, the threshold of TPD depends on the interplay between plasma inhomogeneity, wave damping, and most importantly, resonance detuning due to beam incoherence.
- When the density scale length is large enough, the low-frequency density perturbations can reduce the TPD growth.



- Motivation: experiments on OMEGA study TPD and electron preheat under multiple-beam irradiation
- Thresholds of TPD driven by incoherent beams
- TPD instability driven by multiple crossing beams
- The dependence of TPD threshold on the density scale length
- The influence of low-frequency density perturbations
 on TPD

In OMEGA experiments, the target preheat 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 instability growth rate γ :

$$\begin{aligned} \frac{2(\gamma+\gamma_{e})}{\omega_{p}0} &= -\operatorname{Im}\int \frac{d\vec{k}_{0}}{k_{0}\Delta\theta} \frac{\langle |v_{0}|^{2} \rangle F(\vec{k}_{0},\vec{k})}{2i(\gamma+\gamma_{e})\omega_{p}0 - \frac{3v_{Te}^{2}\left[(\vec{k}_{0}-\vec{k})^{2}-(\vec{k}_{0C}-\vec{k})^{2}\right]}{\sqrt{2}e^{-(\vec{k}_{0}-\vec{k})^{2}}} \\ \text{where } F(\vec{k}_{0},\vec{k}) &= \frac{\left(k_{0}^{2}-2\vec{k}_{0}k\right)^{2}}{4\left[(\vec{k}_{0}-\vec{k})^{2}k^{2}\right]}k_{\perp}^{2} & \gamma_{e^{-}} \text{ damping coefficient,} \\ \gamma_{e^{-}} \text{ damping coefficient,} \\ \Delta\omega &= 3k_{||}k_{0}\lambda^{2}_{De}|\sin\theta_{c}|\Delta\theta\omega_{p0} \end{aligned}$$

- $\int d\vec{k}_0 \rightarrow \int d\theta$: to integrate over the resonant denominator in the integrand
- Large angular width $\Delta \theta$: $(\gamma + \gamma_e) << \Delta \omega$





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



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

$$(\gamma/\omega_{p0})_{\text{inhom}} = (\gamma/\omega_{p0})_{\text{hom}} - \Delta_{\text{inhom}} - (\gamma_e/\omega_{p0})$$

 $\Delta_{\text{inhom}} \sim 1/k_0 L_N$

- 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

$$\gamma_{e} \sim \sqrt{\left(\delta N\right)^{2}} \sim 1\!\big/\gamma_{ia}$$

- *C. S. Liu and M. N. Rosenbluth, Phys. Fluids <u>19</u>, 967 (1976).
- B. F. Lasinski and A. B. Langdon, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50021-77, 4-49 (1978).
- A. Simon et al., Phys. Fluids <u>26</u>, 3107 (1983).

For parameters of OMEGA plasmas, the TPD instability threshold is influenced by the interplay of plasma inhomogeneity, wave damping and resonance detuning due to beam incoherence

 $\left(\frac{\gamma_{e}}{\omega_{p0}}\right)_{coll} = 0.5 \times 10^{-3} \frac{(2/5.3)}{(T_{e}/2 \text{ keV})^{3/2}}$ Plasma wave damping $\frac{1}{2 k_0 L} = \frac{2.1 \times 10^{-4}}{(L/150 \ \mu m)}$ Detuning due to inhomogeneity • Homogeneous 3-wave growth rate $\gamma^0 = \frac{k_0 |V_0|}{\omega_{p0}} = 0.26 \times 10^{-2} \sqrt{I_{14}}$ • Detuning due to beam incoherence $\frac{\Delta \omega}{\omega_{p0}} = 4 \times 10^{-2} (T_e/2 \text{ keV}) \Delta \theta \sin \theta_c$

In OMEGA experiments, the target preheat depends on the overlapped intensity of multiple incoherent laser beams



Two-dimensional fluid-type simulations of TPD have been performed to study the influence of low-frequency perturbations

• The threshold for the absolute instability regime of TPD driven by incoherent beams is observed.

Simulation region 200 $\lambda_0 \times 200 \ \lambda_0$

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F	Parameters	,
	$\Delta \omega >> \gamma_e$	

$$k_0 \lambda_{\rm De} = 0.15,$$

 $k_\perp = k_0,$
 $\gamma_e / \omega_{p0} = 10^{-3}$
 $L_N = 400 \ \mu {\rm m}$

The increase in the angular spread of the driving laser beam reduces the TPD growth



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



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$$\langle I \rangle = 9 \times 10^{14} \text{ W/cm}^2, \ T_e = 2 \text{ keV}, \ n_e = \frac{n_c}{4} \qquad \left(\frac{n_e}{n_0} - 1\right) \sim \frac{I}{\langle I \rangle}$$

The low-frequency perturbations in the electron density can detune the TPD resonance and reduce the TPD growth



 $\langle I \rangle = 9 \times 10^{14} \, \mathrm{W/cm^2}$

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