Nonlinear Absorption of Multiple Laser Beams due to the Two-Plasmon–Decay Instability

University of Rochester
Laboratory for Laser Energetics

$I_{av} = 4 \times 10^{14} \text{W/cm}^2$, threshold $\eta = 1.03$

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The scaling of laser absorption due to two-plasmon decay (TPD) has been obtained for direct-drive inertial confinement fusion (ICF) plasmas on the OMEGA laser.

- *LPSE* simulations with realistic beams (geometry, speckles, polarizations, incidence angles, and intensities) were used to determine the absorption of each laser beam in multibeam TPD.
- Laser absorption due to TPD is not sensitive to the location on the target sphere.
- Absorption is weakly dependent on the beam incidence angle, increasing moderately at larger angles for higher intensities.

*LPSE* Laser-Plasma Simulation Environment

Recent analysis of OMEGA experimental data* demonstrated that laser absorption due to TPD scales with the threshold parameter $\eta = I_{14} L(\mu m)/[233 T_e(keV)]$$^{**}

Absorption due to TPD can reach $\sim$15% for OMEGA conditions

Radiation-hydrodynamics codes do not include absorption due to TPD.

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LPSE was upgraded to model laser depletion due to TPD

- Model solves for laser light (near frequency $\omega_0$) and plasma-wave field (near $\omega_p$) in terms of velocities $V_{0,p} = ieE_{0,p}/m_e\omega_0$ and for ion-acoustic perturbation $\delta N$, and includes background density profile $N_0$

  Laser light
  \[
  i\frac{\partial V_0}{\partial t} + i\gamma_0 \cdot V_0 + \frac{c^2}{2\omega_0} \nabla^2 V_0 + \frac{\omega_p^2 - \omega_0^2(1 + N_0 + \delta N)}{2\omega_0} V_0 = \frac{i\omega_p}{4\omega_0} \left[ (\nabla \cdot V_p) V_p \right]_{\text{Transverse}} \cdot e^{i\delta \omega t}
  \]

  Plasma wave
  \[
  i\frac{\partial V_p}{\partial t} + i\gamma_p \cdot V_p + \frac{3V_p^2}{2\omega_1} \nabla^2 V_p - \frac{\omega_p (N_0 + \delta N)}{2} V_p = \frac{1}{\omega_p} \left[ \nabla(V_p^* \cdot V_0) - (\nabla \cdot V_p^*) V_0 \right] \cdot e^{i\delta \omega t}
  \]

  where $\delta \omega = \omega_0 - 2\omega_p$ – frequency mismatch

L_n = 150 µm; $T_e = 2.5$ keV; $T_i = 1.25$ keV; CH
LPSE simulations used realistic beams with incidence angles and intensities from a ray trace in plasma profiles extracted from the radiation-hydrodynamics code LILAC.

\[ I_{av} = 5 \times 10^{14} \text{ W/cm}^2 \]
Additional laser absorption (up to \(\sim 15\%\)) occurs in a narrow layer near the TPD instability region and saturates on a time scale \(\sim 10\) ps.

Plasma-wave potential

\[
I_{av} = 5 \times 10^{14} \text{ W/cm}^2
\]

Laser absorption

\[
\frac{n_e}{n_c} = 0.25
\]

Absorption reaches nonlinear saturation, and saturated absorption is used in further analysis.
Laser absorption due to TPD was modeled near the quarter-critical surface for five beam configurations corresponding to different locations on the target sphere.

Intensity of driving beams

\[ I_{av} = 4 \times 10^{14} \text{ W/cm}^2, \text{ threshold } \eta = 1.03 \]
Laser absorption due to TPD was modeled near the quarter-critical surface for five beam configurations corresponding to different locations on the target sphere.

Absorption increases moderately with incidence angle but is not sensitive to location.

Absorption is averaged over time and two statistical realizations.

\[ I_{av} = 4 \times 10^{14} \text{ W/cm}^2, \text{ threshold } \eta = 1.03 \]
The scaling of absorption with beam incidence angle has been obtained for three average laser intensities.

Absorption increases moderately with incidence angle for larger intensities.

\[ I_{av} = 5 \times 10^{14} \text{ W/cm}^2, \eta = 1.29, A_{av} = 18.7 \% \]

\[ I_{av} = 4 \times 10^{14} \text{ W/cm}^2, \eta = 1.03, A_{av} = 7.1 \% \]

\[ I_{av} = 3.6 \times 10^{14} \text{ W/cm}^2, \eta = 0.93, A_{av} = 1.2 \% \]

Absorption is averaged over angular range.
Summary/Conclusions

The scaling of laser absorption due to two-plasmon decay (TPD) has been obtained for direct-drive inertial confinement fusion (ICF) plasmas on the OMEGA laser.

- LPSE* simulations with realistic beams (geometry, speckles, polarizations, incidence angles and intensities) were used to determine the absorption of each laser beam in multi-beam TPD.
- Laser absorption due to TPD is not sensitive to the location on the target sphere.
- Absorption is weakly dependent on the beam incidence angle, increasing moderately at larger angles for higher intensities.

The absorption scaling can be readily included in stand-alone ray-trace or radiation hydrodynamics codes.

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* Laser Plasma Simulation Environment