Numerical Simulations of the SSD-Smoothed Laser Beam Filamentation and FSBS in Plasma

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Introduction

- Analysis of the SBS dispersion equation suggests that near-forward SBS can be driven resonantly by the finite bandwidth of a SSD laser beam.\(^1\)

- We have simulated the interaction of narrow-bandwidth (0.14-THz) and wide bandwidth (0.60-THz) light waves with ion-acoustic waves.

- In both cases near-forward SBS occurred, and the beam nonuniformity increased slightly.

A 2-D numerical model for SBS and filamentation was developed

- Our code solves the paraxial light-wave equation coupled with the ion-acoustic wave equation in $t$, $z$, and $x$.

- We used 1-D SSD boundary conditions for the laser beam
  \[ A(x, t) = A_0(x, t)e^{i\phi_{SSD}(x, t)}e^{i\phi_{DPP}(x)} \]

- $A_0(x, t)$: flat-top profile with a rise time of $\sim 100$ ps

- $\phi_{SSD}(x, t) = 3\delta_m \sin[2\pi v(t + \xi x)]$ with parameters relevant to OMEGA:
  - modulation depth $\delta_m = 6.15, 7.89$
  - modulation frequency $v_m = 3\text{GHz}, 9\text{GHz}$
  - grating parameter $\xi = 1.11 \text{ ns/m}$
  - estimated bandwidth $\Delta v \approx 2v_m(\delta_m + 2)$
Propagation through plasma changes the hot-spot intensity distribution.

Intensity on the target plane during 700 ps

$t$, ps

0 1 mm

Vacuum

Plasma 0.5 × 2.5 mm

$T = 2$ keV $n = 14\%_{ncr}$ $I_0 \sim 2.5 \times 10^{14}$ W/cm²
Propagation through plasma slightly increases the nonuniformity of a SSD-smoothed laser beam

\[ \nu = 3 \text{ GHz} \]
\[ \Delta \nu = 0.14 \text{ THz} \]
\[ \sigma_{\text{rms}} = 14.1\% \]
\[ \sigma_{\text{rms}} = 15.5\% \]

\[ \nu = 9 \text{ GHz} \]
\[ \Delta \nu = 0.6 \text{ THz} \]
\[ \sigma_{\text{rms}} = 9.8\% \]
\[ \sigma_{\text{rms}} = 13.0\% \]

\[ t = 700 \text{ ps} \]

\[ \int_{k \geq 0.04 \mu \text{m}^{-1}}^{\infty} P_k^2 \, dk \]
\[ \int_{0}^{k < 0.04 \mu \text{m}^{-1}} P_k^2 \, dk \]

\[ \sigma_{\text{rms}}^2 = \frac{\int_{k \geq 0.04 \mu \text{m}^{-1}} P_k^2 \, dk}{\int_{0}^{k < 0.04 \mu \text{m}^{-1}} P_k^2 \, dk} \]

For low SSD modulation frequency the transmitted light spectrum is widened and reshifted.

\[ I_0 \sim 2.5 \times 10^{14} \text{ W/cm}^2; \quad f\# = 6.7; \quad n = 14\% \ n_{cr}; \]

\[ \nu_m = 3 \text{ GHz}; \quad \Delta \nu = 0.14 \text{ THz} \]

- The blue shifted spectral components are characteristic of near-forward SBS*.

The ion-acoustic spectrum provides further evidence of near-forward SBS

\[ \Delta v = 0.14 \text{ THz} \left< \frac{\delta n}{n} \right> \approx 8\% \]

- Angles \( \theta \) are related to wavenumbers \( k_{sx} \) by \( k_{sx} = 2k_0 \sin(\theta/2) \).

- Energy is distributed uniformly across the spatial spectrum due to angular separation between neighboring lines \( \Delta \theta \), determined from \( k_{sx} = \frac{\omega m}{c_s} \) is \(~0.14^\circ\).
For high SSD modulation frequency the transmitted light spectrum exhibits power exchange between existing lines.

\[ I_0 \approx 2.5 \times 10^{14} \text{ W/cm}^2; \quad f\# = 6.7; \quad n = 14\% n_{cr}; \]
\[ \nu_m = 9.0 \text{ GHz}; \quad \Delta \nu = 0.60 \text{ THz} \]

- We think that spectral broadening is limited by the aspect ratio of the speckles.
The ion-acoustic spectrum proves that power exchange is facilitated by near-forward SBS.

Angular separation between neighboring lines ($\Delta \theta \sim 0.41^\circ$) is consistent with $k_{sx} = \frac{\omega_m}{c_s}$.

Lines, multiple of $\Delta \theta$, indicate that every EM sideband interacts with every other EM sideband.

$\Delta \nu = 0.6 \text{ THz} \left(\frac{\delta n}{n}\right) \approx 2\%$
Resonantly driven SBS was observed in simulation of SSD-smoothed beam propagation

Summary

- For 3-GHz SSD modulation, transmitted light spectrum was widened and red shifted.

- For 9-GHz SSD modulation power was exchanged between the spectral components of the incident light wave.

- In both cases the beam nonuniformity increased slightly.