Numerical Simulations of Stimulated Brillouin Backscatter in the Presence of Transverse Plasma Flow

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Experiments recently performed [1] on the Nova laser at Lawrence Livermore National Laboratory (LLNL) in gas-filled, Scale-1 hohlraums show that laser light scattered back to the lens is shifted away from the center of the lens. It has been proposed [2] that plasma flow transverse to the laser beam, which has been shown to deflect the incident beam in the direction of the flow [3], also deflects the backscattered light in the anti-flow direction.

To better understand the underlying physics of the problem, proof-of-principle fluid simulations using F3D[5]/NH3[6] have been performed. F3D/NH3 is a three-dimensional (3D), nonlinear hydrodynamics and heat transport code coupled to light wave propagation. A variety of simulations have been performed in both two dimensions (2D) and in three dimensions (3D) at wavelength $\lambda_0 = 0.351\,\mu$m, where a Gaussian laser beam with peak intensity $I_0 = 3\times10^{15}$ W/cm^2 propagates through $750\lambda_0$ of CH plasma with electron temperature $T_e = 3$ keV and ion temperature $T_i = 1.5$ keV. The plasma density profile linearly increases from a value of $n/n_c = .075$ at $z = 0$ to a value of $n/n_c = 0.125$ at $z = 750\lambda_0$. Here, $n_c \equiv 9 \times 10^{21}$ cm^{-3} is the density at which light of wavelength λ_0 is reflected. For $0 \leq z \leq 375\lambda_0$ the transverse flow is supersonic, falling from a value of $M_\perp = 1.25$ to $M_\perp = 1.0$ at $z = 375\lambda_0$. For $375\lambda_0 \leq z \leq 750\lambda_0$, the transverse flow is subsonic, falling from $M_\perp = 1.0$ at $z = 375\lambda_0$ to $M_\perp = 0.75$ at $z = 750\lambda_0$. ($M_\perp \equiv u_\perp/C_s$ is the transverse Mach number, with $u_\perp$ the transverse plasma flow and $C_s \equiv (ZT_e/M_i)^{1/2}$ the sound speed, Z the ionic charge state and M_i the ionic mass.) In these simulations, it is anticipated that for light entering at $z = 0$, beam deflection will occur in the supersonic regime via stimulated forward Brillouin scatter [3], and will continue through the subsonic regime via filamentation [3].

These simulations show that plasma flow transverse to the laser beam reduces the reflectivity of the backscattered light, an effect believed to be caused by transit time damping, i.e., the acoustic wave that scatters the incident light is swept out of the laser beam by the plasma flow. This results in a higher effective damping rate on the ion acoustic wave. The transit time damping decrement was determined by measuring the decay in the acoustic wave amplitude at a fixed point in the beam, and was found to be $\overline{\nu}_\perp = 0.027$ for these parameters.

An estimate of the damping decrement can also be made by calculating the amount of time it takes an acoustic wave to traverse the laser beam, $\Delta t \equiv L_\perp / C_s$, where $L_\perp \approx 20\lambda_0$ is the full width at half max (FWHM) of the laser beam. Since $\nu_\perp \sim 2\pi/\Delta t$, it is estimated that $\overline{\nu}_\perp \sim 0.026$.

Transverse flow not only reduces reflectivity levels; it can also displace the backscattered light. In the absence of transverse flow, the peak in both the forward and backscattered light remains aligned at its initial location. However, when there is transverse plasma flow, the forward light is deflected. Simulations in 3D show that the backscatter gain is dominated by the section of the simulation region where the incident light is deflected. This occurs because the backscatter gain was weighted to this region by the increasing plasma density profile.

When the plasma has an axial flow with a scalelength $L_u \leq L$, the backscatter in the back of the box is de-tuned from the backscatter in the front of the box [8]. This mechanism serves to also deflect the backscattered light. When the backscattered light that amplifies along the deflected incident light path is non-resonant with the plasma where the incident light is undeflected, there will be backscattered light reflected at angles similar to those of the incident light, only in the anti-flow direction rather than the flow direction.

Simulations of random phase plate (RPP) [9] beams will also be presented and discussed.

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