Optical Mixing Controlled Stimulated Scattering Instabilities: Progress Toward the Control of Stimulated Raman and Brillouin Scattering Levels with Overlapping Laser Beams in ICF Targets

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We have used the Omega laser facility at LLE, Rochester, as part of the NLUF program, to study the physics of parametric instabilities in overlapping laser beams. Using 10 μm CH exploding foil targets heated to 1.5 - 2 keV, with peak densities below 0.1 n_c, we have simultaneously measured the stimulated Raman and Brillouin scattering reflectivities of the pump beam in the presence of a probe beam 155 degrees apart, whose energy with respect to that of the pump was 1/15:1, 1/2:1 and 1.1:1. We have observed that pump Raman and Brillouin reflectivities decrease systematically when large enough ion acoustic waves are generated via resonant optical mixing of the pump and probe beams at the Mach –1 surface. Comparisons with the Mach +1 and Mach 0 surface focused cases, and at different probe energies, demonstrate the x 2.7 energy transfer at low probe intensities and the nonlinearly saturated nature of the energy transfer at high intensities where Raman backscattering, which is of order 8%, is reduced by a factor of 1.4.

Inertial confinement fusion, based on laser generated implosions, requires that the energy coupling to the plasma be efficient[1], without large reflectivities of the incident light[1], without the generation of large fractions of hot electrons that can preheat the fuel[1], and without excessive energy transfer between beams belonging to different beam cones[2] which intersect, for example, at the light entrance hole of NIF or LMJ scale hohlraums[3]. While much is known about the stimulated Raman and Brillouin backscattering levels (SRS and SBS, respectively) of a single high intensity or interaction beam propagating in small sections of NIF or LMJ scale plasmas, the effects of overlapping high intensity beams on *backscattering* levels in such plasmas has not been studied to any great extent[4], especially when resonant energy transfer between the interaction beams is possible[5,6]. We have embarked upon an experimental campaign on the Omega laser facility to address this problem[7]. This paper describes highlights of the initial phases of this work.

Another major motivation behind this work is the determination of the level of electron plasma wave and ion acoustic wave fluctuations that might exist in a plasma driven by various mechanisms, which play important roles in controlling the evolution of backscattered SRS and SBS[8]. Apart from directly probing all these plasma modes simultaneously via very many Thomson scattering stations[4,6], resolving their phase space evolution with high temporal resolution as well, one may rely on optical mixing techniques to *generate* the fluctuations themselves. This way, by increasing the amplitudes of the optical mixing generated waves, one can observe at what point backscattering levels are significantly affected and thus have a measure of what may be preexistent in the plasma due to internal processes. We have done this on Omega using identical frequency pump and probe interaction beams in flowing exploding foil plasmas, where a resonant interaction and optical mixing generated ion acoustic waves (IAW) are possible at the Mach –1 surface (where the flow is *towards* the incident pump wave). This is where the equal frequency electromagnetic waves are resonant with ion acoustic waves of zero frequency since the sound speed is compensated for by the flow opposing it.[6] We demonstrate resonant energy transfer by comparing Mach 1 and Mach –1 focused beam cases, as well as to cases where the beams cross at the stagnation point which is at the peak of the density profile. By varying the focusing positions of the two interaction beams and the intensity of the probe, we have identified cases where SRS and SBS reflectivities are significantly reduced due to the existence of the optical mixing generated IAW.

The experimental setup was as follows. Two sets of three 500J, 1ns, stacked heater beams illuminated each side of a 10 μm CH foil target to generate and heat the exploding foil plasma for two nanoseconds. The nominal intensity of these beams was 10^{14} W/cm^2. Two interaction beams were also used which started 1.5 ns after the start of the heaters and ended 0.5 ns after the (2ns) heaters were shut off. The interaction beams were at 12.5 degrees each with respect to the target normal, and 155 degrees apart, with the pump energy being maintained at 500J, while the probe was varied from 1/15, 1/2 and 1.1 times that of the pump. The intensity of the pump beam was 5×10^{14} W/cm^2. All beams, heaters and interaction, had DPPs but no temporal smoothing such as SSD. The interaction beams were crossed at the density peak and at 500 μm to either side of the peak. The Mach 1 surfaces were expected to be at 350 μm from the peak, at times of interest, according to hydro simulations. But since the Rayleigh lengths of the interaction beams were of the order of a millimeter, we chose to focus the beams at plus and minus 500 microns away from and at the peak so as to better isolate the three cases. Plasmas such as these have been characterized in previous experiments at LLE.[9]

The diagnostics used were two full aperture backscattering stations (FABS). These include streaked spectrometers for SRS and SBS as well as calorimeters for both. We ascertain the plasma density from the Raman spectrum and the temperature from KCl microdots and X-ray spectroscopy.[9] Hydro simulations confirm that the peak densities we achieved at times of interest were around 0.08 n_c, where n_c is the critical density of $3\omega_0$ laser light. The temperatures were between 1.5 and 2 keV. Some of the lowest order physical phenomena one might expect when a sufficiently high intensity probe beam is introduced into the plasma with a pump beam already present are: additional heating, probe ponderomotive force caused density perturbations, and wherever resonance is possible, optical mixing with the pump and the generation of an IAW with varying amplitude, proportional to the square root of the product of the intensities of pump and probe. We can control the extent to which these may occur by changing the focusing position of the interaction beams as well as the energy of the probe beam.

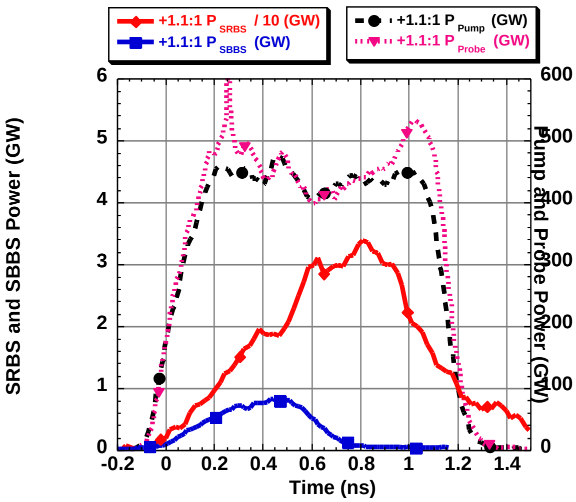


FIG. 1(a)

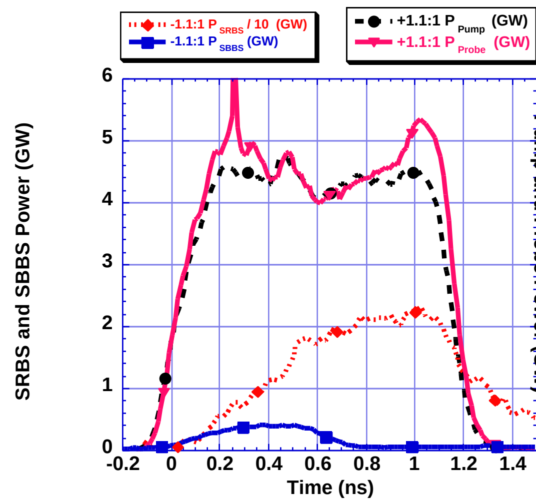
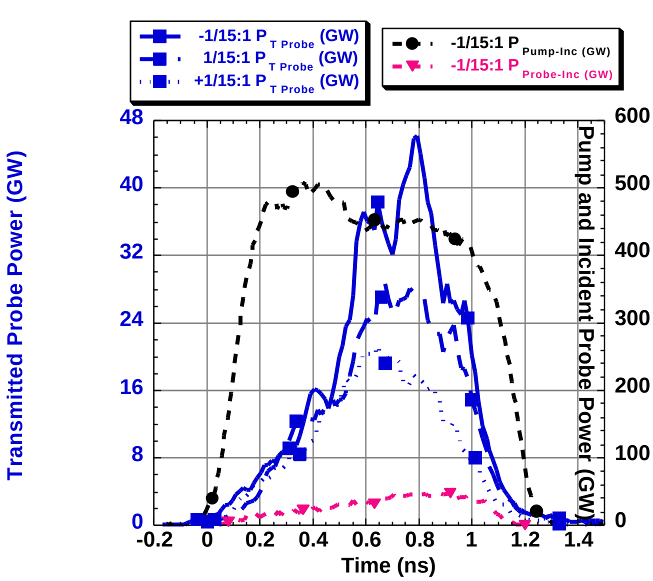
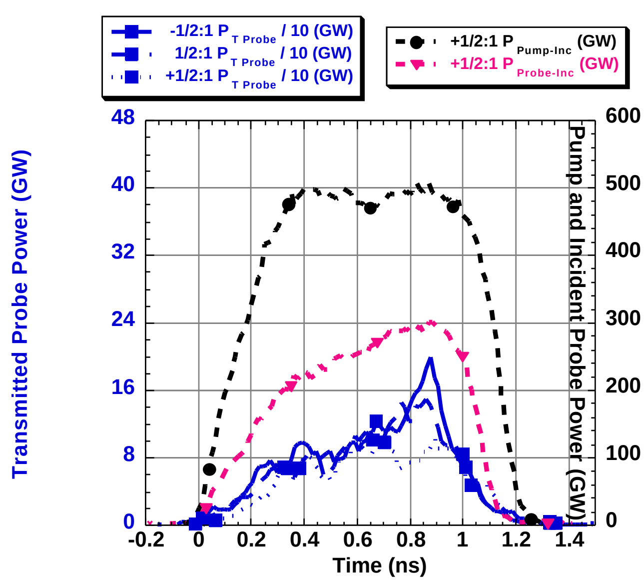


FIG. 1(b)

Figs. 1 (a) and (b) demonstrate the optical mixing controlled stimulated scattering instability (OMC SSI) effect. The probe to pump energy ratio is 1.1:1 in this case, and the reduction of both SRS and SBS backscattering levels when the beams are focused at –500 μm (b) as compared to their levels away from the resonance surface at +500 μm (a). In addition, the resonant energy transfer from the pump to the probe beam is shown in figures (2) (a) and (b) for probe to pump energy rations of 1/15:1 and 1/2:1, respectively. By comparing the transmission levels of the probe when focused at –500 μm to those at +500 μm, (solid vs dotted curves) the resonance





effect is laid bare.

Figs (3) show the pump SRS reflectivity and probe transmission as a function of focusing position. The factor of 1.4 reduction in SRS reflectivity when comparing minus to plus 500 micron focusing is evident at the 1.1:1 energy ratio, while almost 100% transmission due to resonant energy transfer is seen at the 1/15:1 probe to pump energy ratio in Fig. 3(b). The black squares correspond to pump on and probe off focused at the center in Fig 3(a) and to probe at 1/2 and pump off focused at Mach =-1 in Fig 3(b). They are good measures of shot to shot reporducibility and thus experimental error, which is seen to be of the order of 10%.

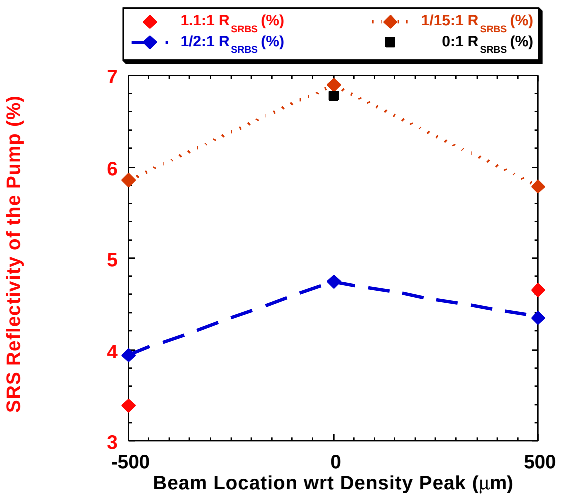


FIG. 3(a)

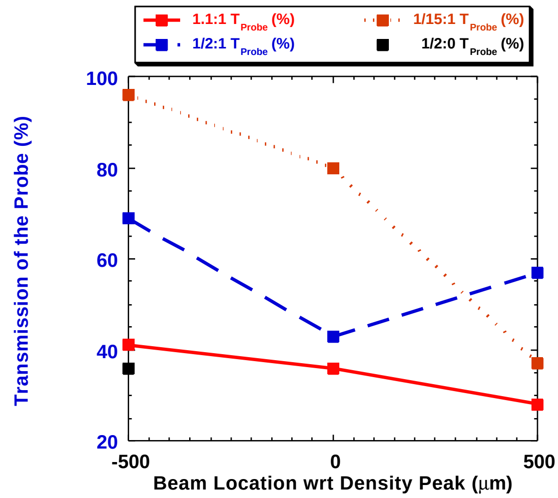
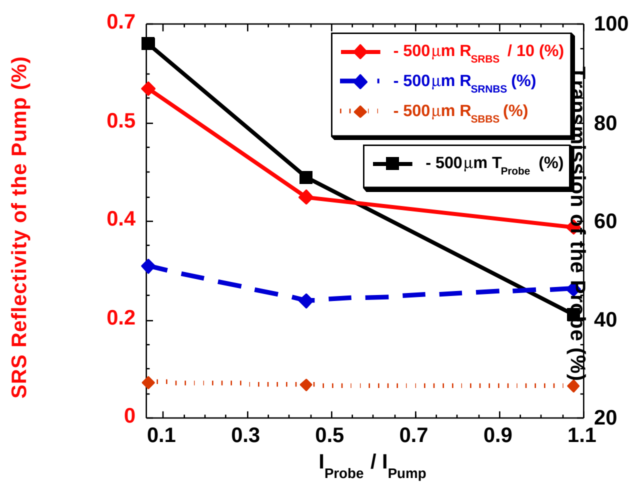
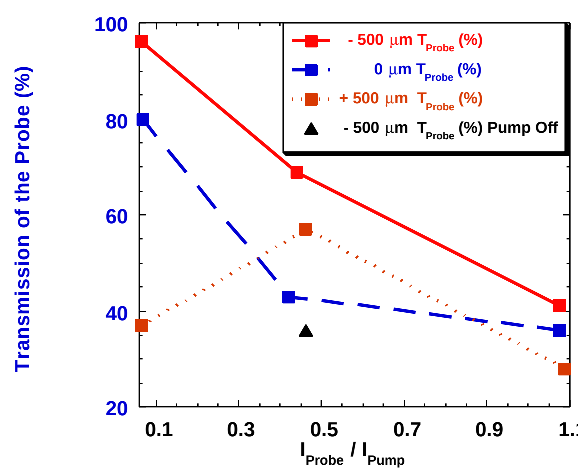


FIG. 3(b)

Figures (4) show the behavior of the pump SRBS (Raman backscatter), SRNBS (Raman near backscatter at 25 degrees) and SBBS (Brillouin backscatter) and probe transmission as a function of probe to pump energy ratio. Note the nonlinear nature of the energy transfer at 1:1 and SRS reduction even when the probe energy is half that of the pump.





In future experiments we will attempt to determine the precise ratio of probe to pump energy necessary to obtain nonlinear energy transfer and backscattering reduction in Brillouin dominated regimes as well as Raman dominated regimes such as here, where Raman reflectivities were of order 8% and Brillouin, 0.1%. Theoretical interpretations of these results relying upon diverse physical effects,[8,10-12] will be published elsewhere[7]. The dominant effects are: 1) the spatially dependent pump and probe beam collisional absorption/damping rates, 2) the velocity gradient near the Mach 1 point and its evolution as a function of time, 3) pump depletion of both probe and pump beams including their individual hot spot dynamics and filamentation and 4) nonlinearities in the IAW response which result in long wavelength fluctuations in the plasma which then dephase the SRS and SBS backscattering of the pump.

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