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Experimental investigation of short light pulse amplification using stimulated Brillouin backscattering

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Introduction

The study of energy coupling between interacting laser beams in the plasma medium is of primary importance for different scientific applications. In the ICF frame an accurate modelling of the non linear processes occurring at the entrance of the holharum is needed. This is the region where typically energy exchange between beams can influence the light distribution an so the symmetry of illumination. Conversely energy exchange processes can be exploited to transfer the energy from a long laser pulse to a short one in order to amplify.

In both cases the occurrence of energy exchange is due to three waves resonant coupling: the interacting laser beams participe as two electromagnetic waves, the third wave is a plasma wave: an ion acoustic wave (Stimulated Brillouin Scattering or SBS), or an electron plasma wave (Stimulated Raman Scattering, SRS).Most of the ICF-oriented studies have been exploring energy exchange of long laser pulses through Stimulated Brillouin Backscattering[1]. The possibility of manipulating light at high intensities is an interesting reason to study energy transfer between beams (fig.1). In the effort of reaching higher laser intensities to exploit new physics domains the plasma medium (environment) is a good candidate for amplification to take place since it can withstand high density power (>>GW/cm^2) and large heat loads. These would be a limitation of conventional media due usual optical components damage treshold. A scheme based on the Stimulated Raman Backscattering has already been studied and experimentally tested[2]. Compression in the SBS-weak coupling regime as been proposed as well[3]. New interesting features are those of SBS in the strong coupling regime and these can be exploited in order to achieve light amplification[4]. The strong coupling regime is characterized by low temperatures (hundreds of KeV) and high intensities, yet not relativistic ($I_{14}\lambda_0^2 > 10^{-2}\, T_e^{3/2}[\text{keV}]\, n_c/n_e\, [1-(n_e/n_c)]^{1/2}$).

Under these conditions the plasma response is described by a quasi-mode forced on the ion wave with ω_{sc} about the order of or larger than plasma ion frequency ω_{pi} . The advantages of this scheme can be identified in a strong robustness of the phenomenon with respect to plasma inhomogeneities or frequency mismatch and in the absence of kinetic effects during amplification and short interaction length.

Experiment

A first attempt to prove the feasibility of light amplification in the strong-coupling regime SBS was carried out at the LULI 100 TW facility (France). Two (quasi-counterpropagating) beams, a 'seed', to be amplified, and a 'pump', to be used as reservoir of energy, were crossed at an angle of 20° in a preformed plasma medium (fig.2). The plasma was created from the ionization of a gas jet by a 'creation' laser beam; after a RPP this beam was focused to a 0.3 mm^2 focal spot just above (1 mm) the nozzle of a gas jet and a pulse length of 450 ps FWHM. The pulse arrived 1 ns before the interaction to allow plasma homogeneization. The plasma characteristics (density distribution, temperature) were optimized varying the physical parameters: nozzle diameter, type of gas (Argon, Nitrogen and Helium were used) and gas pressure. The seed beam (50 mJ, 400fs FWHM) was focused down to 20 μm which resulted in a $\sim 10^{15}$ W/cm^2 intensity, while the pump beam (2 J) was used at different pulse temporal lengths (0.3-30 ps) and waists (10-100 μm) which resulted in an intensity larger than the one of the seed (10^{15}-10^{16} W/cm^2). For both beams the transmission signal was imaged as well as its spectrum. The first gave an idea of the beams profiles as of the transmitted beam energy, the second gave information on the amplification\depletion effectiveness over just a particular bandwith of frequencies. An autocorrelator was set up in order to measure the temporal length of the seed beam and confirm that when amplified the seed beam conserved a short duration. Additionally an interferometer could provide information about the pump beam spatial and temporal coherence. A clear evidence of light amplification was observed throughout the experimental campaign under particular conditions (fig. 3). In such condition the signal of the transmitted seed beam was observed increasing after the interaction with the pump in all the diagnostics; under the same conditions the pump transmission signal was observed depleting.

Many parameters were involved in the interaction, among these the temporal delay between the two beams, the plasma density, the pump beam duration and the polarization of the beams. Measurements were performed in order to decouple the parameters.

Analyzing the results from shots on an Argon plasma at 50 bar with the pump beam duration set at 3.5 ps we could infer that the best gain was obtained for a zero delay between the beams and we could observe how at higher delays the gain decreased until there was no more superposition of the two beams and therefore no amplification. When the gas pressure was varied, and so the plasma density, we observed a considerable gain over different pressure values. The parameter involved in the amplification which gave evidence of the electromagnetic coupling is the relative polarization between the two beams. When a polarizer was in the pump beam path the detected signal was small compared to the one we observed when the polarizations were parallel.

We have started performing numerical simulations exploring the same range of parameters used in the experiment. Preliminary results show that both one-dimentional PIC and 2D Hybrid/Helmolz codes predict amplification of the seed beam. Hybrid code shows as well the pump beam depletion.

Conclusion

Using the LULI 100 TW facility we were able to give a first experimental demonstration of the feasibility of light amplification of short pulses using a Stimulated Brillouin Backscattering scheme in the strong coupling regime. Amplification of the seed signal over ten times was obtained and the influence on the process of a number of parameters was analyzed. Numerical simulations are in progress to interpret the results.

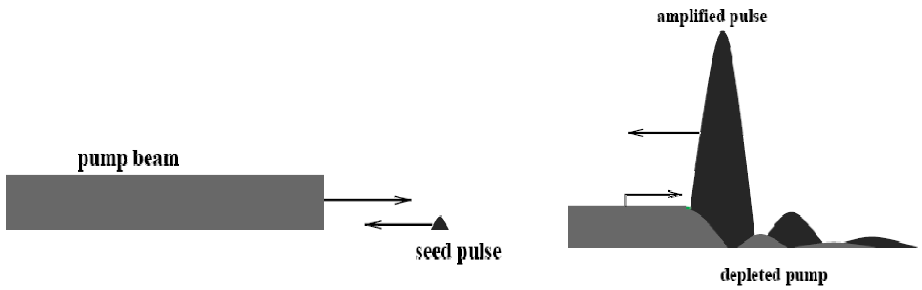

fig.:1 Principle of amplification of counterpropagating beams

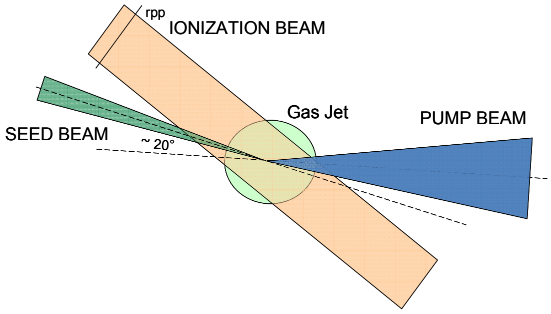

fig.2 Experimental setup

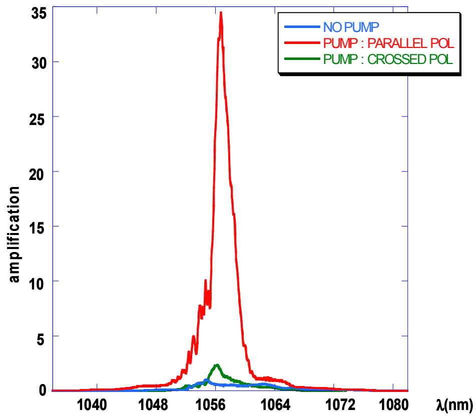

fig.3 Typical amplification result

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