INTERACTION EXPERIMENTS IN LONG AND HOMOGENEOUS PLASMAS

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ABSTRACT

Interaction mechanisms between a high intensity laser beam and a long homogeneous underdense plasma are studied both in the contexts of laser fusion and new particle accelerator concepts Experiments are performed in long plasmas generated by explosion of a thin foil irradiated by a high intensity laser beam Main results on the interaction processes in such plasmas are presented for short wavelength lasers (λ = 0.53 and 0 26 μm).

I INTRODUCTION

Interaction mechanisms between a high intensity laser beam and a plasma have been studied for many years in the context of intertial confinement fusion It has been shown that short wavelength lasers have many advantages Collisional absorption, heating most of the plasma electrons, is increased to very high values of the order of 80% to 90% At the same time deleterious effects as Brillouin scattering, two plasmon decay, Raman scattering and instabilities near the critical density are greatly reduced If Brillouin only scatters a fraction of the laser energy away from the plasma, other instabilities generate high amplitude plasma waves which in turn accelerate a small fraction of the electrons to very high energies Not only do these electrons lower the hydrodynamic efficiency of the interaction but they can heat the D T fuel before a sufficient compression has been reached An open question is to know what will happen to these instabilities in the long ($\sim$ 1 cm), hot and quasi homogeneous plasmas ($\sim$ a few 100 eV) expanding in front of the targets needed in future compression experiments

On the other hand, plasma waves generated by forward Raman instability can have a very high phase velocity close to c and thus accelerate electrons to very high energies In fact, electrons with energy up to a few MeV have already been detected in laser target interactions Advantages of forward Raman instability against the "usual" beat-wave technique is that it uses only one wavelength laser and that it does not need a very accurate plasma density matching But as forward Raman is an instability, one may need a high intensity laser to excite it in the low density plasmas necessary to obtain high phase velocity plasma waves

An experiment has been developed in order 1) to generate long (1 mm) and homogeneous plasmas 2) to study the laser plasma interaction mechanisms in these conditions

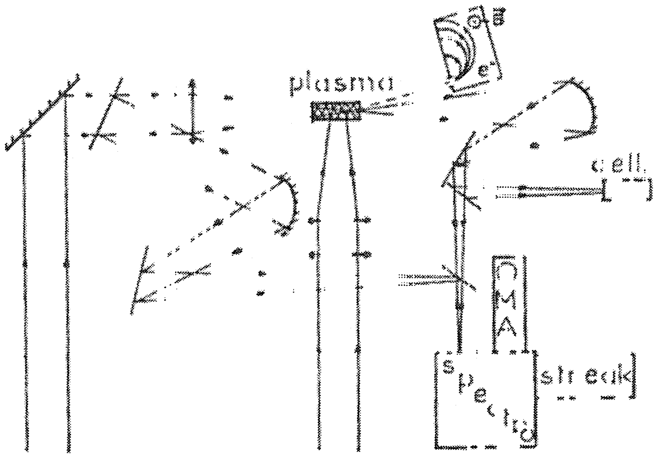

Figure 1
Experimental set up

2 EXPERIMENTAL SET UP

The experimental set up is schematically shown on Fig 1 We used the neodymium laser of the GRECO ILM delivering two 90 mm diameter beams with up to 80 J per beam at 1 053 μm for 600 ps (FWHM) pulses The first beam is frequency doubled [40 J at 0 53 μm for 500 ps (FWHM) pulses] and focused with either two cylindrical lenses (f = 700 and 750 mm) or one cylindrical (f = 11 m) and one doublet (f = 250 mm) on a thin (e = 2 000 Å to 1 μm) plastic (CH) foil The focal spot looks like a 1 mm long and 200 μm high rectangular area and the intensity goes up to 2 10^{13} W/cm^2 The typical density and temperature profiles of the expanding plasma at different times during or after the laser pulse are shown on Fig 2 The maximum plasma density can be chosen by varying the delay between the first beam and the interaction beam or by changing the initial foil thickness

The interaction beam is then focused along the plasma (i e along constant densities) by a f/2 7 doublet (f = 250 mm) or a f/8 lens The maximum intensity at focus is 2 10^{15} W/cm^2 at λ = 0 53 μm and 10^{15} W/cm^2 at λ = 0 26 μm the two wavelengths used in these experiments

The main diagnostics are the following :

Time resolved and time integrated measurement of backreflected light through the focusing lens

Time integrated measurement of transmitted light into a f/8 collecting system

Time resolved measurement of the backward and forward Raman spectra

Measurement of the high energy elctrons emitted from the target between 30 keV and 250 keV

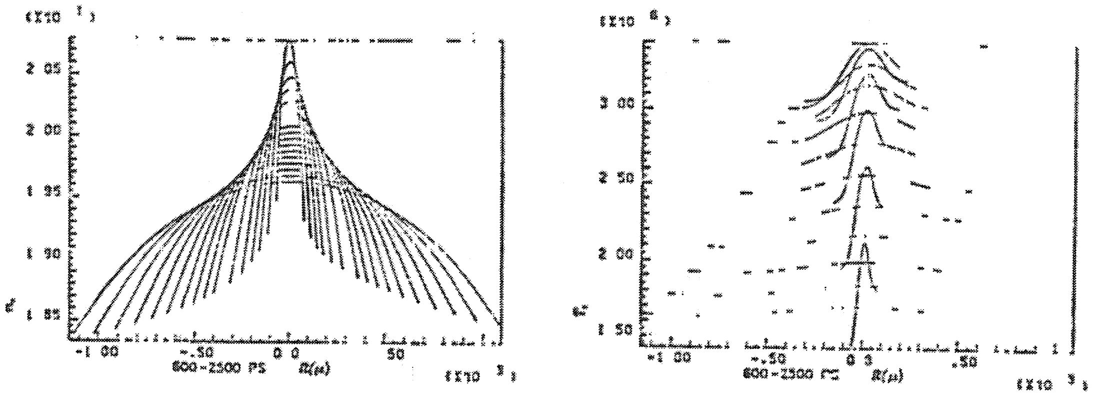

Figure 2

Density and temperature profiles from 1D simulation at different times

Parameters of the simulation are CH foil e = 2000 Å λ = 0 53 μm

600 ps FWHM I = 10^{13} W/cm^2, the maximum of the pulse is at 900 ps

3 EXPERIMENTAL RESULTS

The density and temperature of the preformed plasma can be obtained from the measured backward Raman spectra From the relation $z_1=z_0\ z_p$ where z_1 (z_0) is the frequency of the scattered light (incident light) and z_p is the plasma frequency proportional to $n_e^{1/2}$ very close to the plasma wave frequency, one can determine the density of the plasma from the measurement of z_1 Examples of backward Raman spectra obtained at λ = 0 53 and 0 26 μm are shown on Fig 3 together with the corresponding plasma densities The density range is shown on Fig 4 as a function of the delay between the two pulses and of the initial foil thickness

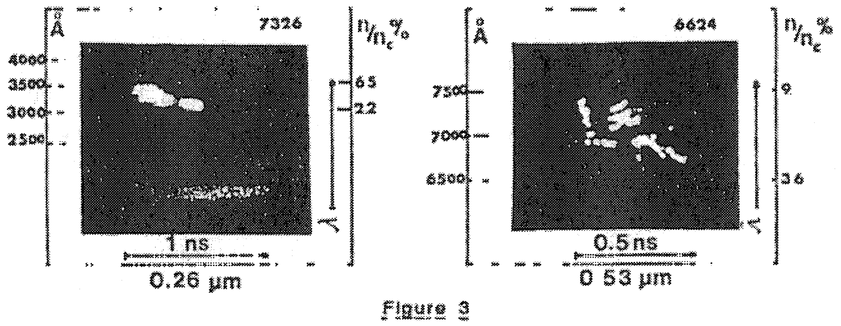

Figure 3

Two examples of backward Raman spectra at λ = 0 26 μm and λ = 0 53 μm

The corresponding plasma density is indicated on the right

For the long delay as well as thin foils, only low densities are observed The low density limit of the spectra can be attributed to Landau damping which occurs for short wavelength plasma waves compared with the Debye length ($k l_D \approx 0\ 25$), where $k=k_0+k_1$ We thus obtain temperatures between 100 and 250 eV At these temperatures the plasma is highly collisional and all the other results confirm this effect

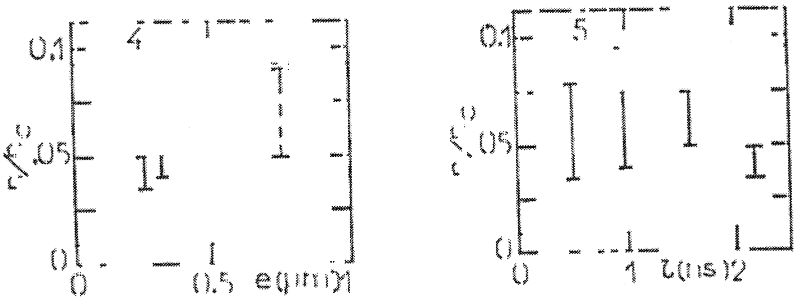

Figure 4
Spectral range in n/n_c of backward Raman emission vs delay between the two beams and initial foil thickness. $\lambda = 0.53$ µm, $I = 4\ 10^{14}$ W/cm^2

Back reflection through the focusing lens is always less than 0.1%. The back reflected energy appears in very short bursts often less than the 20 ps time resolution of the system. An example is shown on Fig. 5. Transmission through the plasma shown on Fig. 6 is low and compatible with a 250 eV temperature. No forward Raman could be seen in these experiments performed with short wavelength lasers. The collisional threshold for this instability is proportional to $(n/n_c)^{3/2}/\lambda^4\ T_e^3$. For these low temperature plasmas the ratio between the Raman wave phase velocity and the thermal velocity is of the order of 10 so that no background electrons can be trapped and accelerated in the wave.

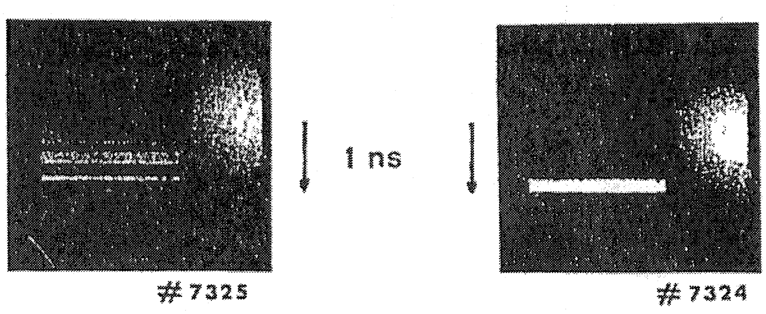

Figure 5
Two examples of time resolved backreflected signal near the fundamental frequency

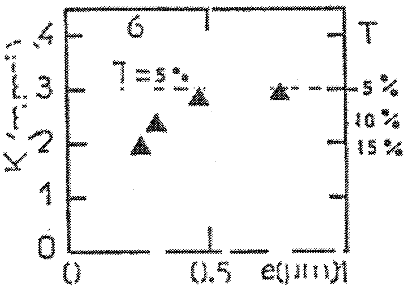

Figure 6

Transmission and absorption coefficient of the plasma vs initial foil thickness
$\lambda = 0.53$ μm and $I = 4\ 10^{14}$ W/cm^2

4 CONCLUSIONS

Explosion of thin foils irradiated by a high intensity laser beam generates long and homogeneous plasmas (1 mm, $n_e = 10^{19}$ 10^{21} cm^{-3}) The maximum density of the plasma during the interaction with a second beam can be adjusted by changing the delay between the two beams or the initial foil thickness At the available laser energy the temperature of the plasma is of the order of 100 to 250 eV and the plasma is highly collisional The generation of high phase velocity plasma waves by forward Raman scattering has to be achieved in hotter plasmas and/or at longer laser wavelength Experiments will soon be performed in this direction

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Discussion

H. Hora, University of New South Wales

I would like to refer to the Raman mechanism and to the result of Paul Drake at Livermore [1] that Raman instabilities do not contribute much to the energy transfer; your transfer by plasma waves (similar to Joshi's, this conference) may well give the MeV electrons (with one laser frequency) as we (this conference) see from the strong longitudinal Langmuir fields. Could you please comment under what condition you are expecting a strong and dominating Raman mechanism.

[1] P. Drake, ECLIM '87 Conf Prague, May 1987.

Reply

Drake experiments took place in inhomogeneous plasmas and we want to study what happens in long and homogenous plasmas where instabilities can grow over a long distance. To preferentially excite forward Raman scattering compared to backward Raman scattering one needs a hot plasma so that Landau damping becomes efficient for short wavelength plasma waves