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STUDY OF SECOND HARMONIC GENERATION IN FILAMENTARY PLASMAS

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The study and the possible control of filamentation and whole beam self focusing of laser light interacting with a plasma are key issues for inertial confinement fusion. Our group has been involved in this study for several years. In a first phase we performed measurements mostly on the laser transmitted and scattered light (at the fondamental frequency). In a second phase the experimental work was addressed to the second harmonic emission as a diagnostic for filamentation.

The maximum efficiency of second harmonic generation (SHG) in laser-plasma interaction is expected and in fact was observed at plasma density close to the critical density where electron plasma frequency $\omega_{pe} \approx \omega_0$ makes it easiest to excite plasma waves at frequency ω_0 with consequent possibility of harmonic multiplicaton. At the critical region SHG is strictly related to resonant absorption which strongly enhances electron plasma waves at frequency close to ω_0. However it has been shown both theoretically [1] and experimentally [2-3] that even at density much lower than the critical one, 2ω emission can be observed, provided density gradients are present into the interaction region. In this case 2ω current originates from the combination of electron motion at ω_0 and density components oscillating at ω_0 in the density gradient. In the current term both density gradient and field gradient are strictly connected:

$$\mathbf{J}_{2\omega} = i\, e^3 m^{-2}\, \omega_0^{-3} \left[\varepsilon_0^{-1} (\nabla n \cdot \mathbf{E})\mathbf{E} + (n/4)\, \nabla(\mathbf{E} \cdot \mathbf{E}) \right] \;,$$

where $\mathbf{J}_{2\omega}$ is the current density for second harmonic emission; ε_0 is the dielectric constant and $\mathbf{E}$ the electric field at the angular frequency ω_0; n the electron density.

For this reason SHG in underdense plasmas is strongly enhanced by self-focusing and filamentation which typically create strong field and density gradients and conversely SHG is a suitable diagnostic for those instabilities. We studied SHG in sparks produced by laser breakdown of gases in conditions where filamentation and self-focusing were observed[3,4]. In those conditions also the conversion efficiency v/s laser intensity and gas density was measured as well as the polarization of SHG v/s laser polarization [3]. Theoretical calculations on angular distribution were compared with experimental results [5].

More recently we studied SHG in plasmas produced by direct irradiation of thin foil targets with a focused laser beam. The experiment was designed on the basis of a self-similar 1-D model [6] giving us a rough estimate of the maximum foil thickness allowing the plasma to become underdense before the peak of the pulse. From the same model we also calculated the expected density profiles and temperatures during the pulse. The plastic used to prepare the thin foils was polyvynyl formal and the target thickness used in the experiment was in the range 0.1 - 1.8 µm. The thin foil was irradiated at 1064 nm laser wavelength with a pulse of 3 ns FWHM at an irradiance between 10^{12} and 5 10^{13} W/cm^2. The laser beam was focused perpendicularly to the target plane with an f/8 lens. The laser bandwidth was 0.07 nm. The contrast ratio (prepulse to main pulse energy ratio) was about 10^{-4}.

Several instruments were used to investigate the interaction and particularly to analyse the re-emitted light, including an optical streak-camera to get time-resolved spectra and time-resolved 1D images with a time-resolution up to few picoseconds and a gated image intensifier, to get 2-D images within a 120 ps gated window. X-UV time-integrated measurements were done by a pin-hole camera and a filtered diode.

Interesting results were obtained from the study of 2ω light emitted at 90° with respect to the beam axis. Time resolved images showed that this emission came from a large region of underdense plasma and time resolved spectra were consistent with the assumption that side-emission was due to the sum frequency of the incoming laser light with the Brillouin backscattered light [7] as previously suggested by J.A. Stamper and co-workers [8]. Time resolved spectra showed that the initial position of the 2ω line had a red shift of 4 Å attributable to Brillouin backscattering at temperature of about 600 eV, which was expected for our plasma. The increase in the red shift at later time, as well as the increase in the bandwidth were explainable in terms of Doppler shift due to the plasma flow from the target [7].

The sum frequency emission we evidenced can be used in principle as a diagnostic in place of direct measurements on stimulated Brillouin backscattered light. This method could be advantageous because 2ω light is spectroscopically well separated from the fundamental, much better than the backscattered light. Furthermore, the experimental detection is generally more suitable at 90° than backward. Finally, imaging the plasma laterally in sum-of-frequency light we can see where SBS is stimulated.

Measurements on second harmonic emitted forward in the interaction with underdense plasmas from thin foils are in progress. The angular distribution was found to be mostly concentrated in the laser beam cone as already observed in gases. The conversion efficiency is strongly dependent on the target position. It has a maximum when the target is behind the best focus (experimentally determined) of about 0.5 mm i.e. twice the focal depth of our lens. The efficiency drops more than one order of magnitude at the best focus and three order of magnitude 0.5 mm ahead the best focus. This fact suggests that self- focusing and filamentation play a leading role: in fact these instabilities can grow better when the beam is focused ahead the plasma, as shown in Fig 1.
The cross section of the interaction region was imaged out and time-resolved with both an optical streak-camera and a gated image intensifier. Narrowband filters allowed only second harmonic light to reach both instruments. Images obtained with target in the position of maximum conversion efficiency showed in the central part an intense 2ω source of smaller size than the laser spot and structured in filaments whose number and positon varied shot-by-shot. The external part of the pictures showed fringes whose interpretation is still uncertain. Tentatively we attributed them to interference between different regions of the filamentary channel which are out of focus for the imaging lenses. A typical example of those images is given in Fig.1.

Images from streak-camera showed that fringes sometime evolves regularly, sometime in a very cahotic way, suggesting that a sort of "unstable filamentation" may occur in these conditions. Further work has to be done to clarify some aspects of forward second harmonic generation.

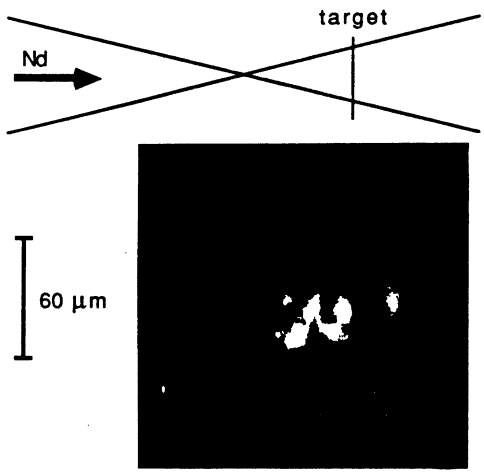

Fig. 1. Cross section of the interaction region imaged by the second harmonic light emitted forward. The image was obtained with a gated image intensifier using a narrowband filter at 5320Å. The 120 ps gate-window was centered at the peak of the laser pulse. Target: 1. μm plastic foil. Target position: 0.5 mm behind the best focus. Nominal irradiance on target: 2 10^{13} W/cm^2. Filaments and related interference fringes are apparent.

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