REFLECTION AND TRANSMISSION OF HIGH INTENSITY FEMTOSECOND LASER PULSE FOCUSED ON VERY THIN PLASTIC FOILS

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ABSTRACT

The 150 fs pulse of the LOA Ti:Sapphire laser has been focused at an intensity of 5×10^{17} W/cm^2 on a 800Å plastic foil. The reflected and transmitted laser radiation resulted strongly affected by Self Phase Modulation effects. Even if the measurements were time integrated, the analysis of the spectra give information on laser plasma interaction at different times.

A peculiar characteristic of laser produced plasmas with femtosecond pulses is the negligible hydrodynamic expansion during the pulse. In fact, the scale length of the plasma density perpendicular to the target surface, given by $L = c_s \Delta t$, is much shorter than the vacuum wavelength λ of the impinging laser radiation, that is : $\lambda \gg L$, where c_s is the sound velocity, and Δt the pulse duration. In these experimental conditions the interaction geometry is particularly well defined. Thus the laser radiation impinges at a given angle θ on a fairly flat plasma surface having a sharp density profile.

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The majority of the experiments reported so far have been performed by focusing the laser pulse on thick targets, or films coated on transparent massive supports. The plasma produced in this conditions can be divided in three regions. The first region consists of the plasma expanding in the vacuum, whose typical extension is few hundred of Å ngstrom. The second, whose electron density is that of the solid target times the average ionization degree, extends in the overdense plasma over a length of the order of the skin depth, typically $l_s \approx 200$Å. The third region, not directly reached by the laser e.m. field, is determined by heat diffusion processes and extends over several thousands of Ångstroms.

However, this structure can be strongly modified if target pre-heating occurs, due to the presence of laser pre-pulse. In the case of laser systems based on the chirped pulse amplification technique[1], laser pre-pulse can arise from imperfections in the compression stage of the laser. In addition, pre-pulse can also arise from amplified spontaneous emission[2]. This pre-pulse can produce a tenuous plasma in front of the target, before the arrival of the main pulse, deeply changing the interaction conditions.

In order to minimize this effect we used targets consisting of very thin ($d <$ 1000Å) plastic (FORMVAR) foils. Due to the high transparency of these targets, the threshold intensity for damage and consequent plasma formation is expected to be relatively high compared to the estimated pre-pulse intensity level in our experimental conditions. Another characteristic of this type of target for the laser pulse regime considered here is the higher temperature achievable, during the interaction, as a consequence of minor energy losses due to heat conduction. In fact, the thermal conduction length is much larger than the target thickness.

The experiment we present here was performed at the Laboratoire d'Optique Appliquée by using a femtosecond Ti:Sapphire laser system[3]. We studied the interaction processes of an intense femtosecond pulse in a very short density scale length plasma. The experimental results, concerning the correlation of X-ray and second harmonic emissions with the laser polarization, have been presented elsewhere[4]. In this paper we report on reflection and transmission of laser radiation impinging on the very thin foil. The data add a piece of new information on laser plasma interaction in experimental conditions not yet investigated enough.

The Ti:Sapphire laser pulse ($\lambda \approx$ 8040Å, $\Delta t \approx 150$fsec, $E \approx 10$ mJ on target) was focused ($\phi \approx 5\mu$m, spot diameter) on 800Å FORMVAR foil at intensities up to 5×10^{17}W/cm^2. The angle of incidence was 20 deg. The beam was focused by means of an f/4 reflective optics in an off-axis configuration. The specularly reflected and transmitted laser radiation was collected and sent part to photo diodes, part to CCD cameras for spectral analysis or imaging. All measurements were time integrated.

The measured transmittivity resulted $\approx 5\%$, that is at least 100 times higher than the expected theoretical value, even taking into account the pre-pulse energy passing through the target, before plasma formation. This suggests different possibilities : a) the transmitted radiation is partially refracted, passing through the target externally to the critical region; b) the leading front of the laser pulse passes through the target, before the plasma formation. On the other side, if we exclude effects of overdense penetration, or relativistic self-focusing[5] since the laser intensity is below the relativistic threshold, it is even more difficult to consider that radiation could pass the target through channels due to ordinary self-focusing/filamentation. In fact the filament formation times range in the hydrodynamic time scale, much larger than the 150fsec laser pulse duration.

We observed that the reflectivity increases with the laser intensity. According to the Drude model applied to the produced plasma, this corresponds to an increase of the plasma temperature with the laser intensity.

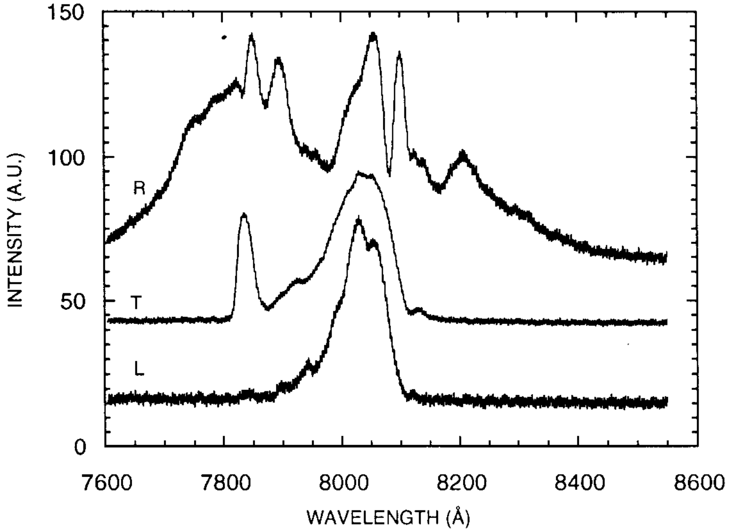

Figure 1. The spectra of the impinging (L), reflected (R), and transmitted (T) laser radiation. The intensity of the impinging laser radiation is 5×10^{17}W/cm^2.

The laser radiation transmitted through the target has basically the same spectrum as the one of the impinging radiation (see Fig.1). However, an intense up-shifted component, as previously observed in similar experiments[5], and a down-shifted component much weaker are also visible in the spectrum.

Such spectral components can be explained in terms of Self Phase Modulation (SPM) of the laser radiation passing through a plasma whose electron density increases in time during the leading front of the laser pulse (up-shifted component) and decreases during the tailing front (down-shifted component). A qualitative but quite exhaustive explanation of the observed phenomenon can be obtained by plotting, versus the time, the laser pulse, the electron density n_e and the per cent shift of laser frequency, due to SPM: $\Delta\omega/\omega = (Z/2c(1-N)^{1/2})\, dN/dt$. In the previous formula Z represents the longitudinal plasma extension, c the speed of light in vacuum, and $N=n_e/n_c$ (n_c being the critical density for the impinging laser radiation). In agreement with simulation results, the electron density increases with a characteristic time of the same order of that of the leading front of the laser pulse, and decreases with a much longer time scale (≈10 times longer). The laser radiation can be transmitted until the electron density is below the critical density ($n_e\ {}^2\ n_c$), resulting progressively more up-shifted. At later times the plasma is completely opaque, until the density decreases below the critical value. This happens on the tail of the laser pulse, due to the longer time of the density decrease. The resulting down-shift is smaller due to the minor value of dN/dt. Also the intensity of such component is lower, because it is produced in the tail of the laser pulse.

Therefore the spectral analysis of transmitted radiation actually provides information on the interaction with the target at different times: the unperturbed component corresponds to the laser radiation passing through the target before the plasma formation; the up-shifted component is transmitted during the leading front of the pulse; the down-shifted during the tailing front.

We notice that the laser spectrum was as wide as two times the Fourier transform limit. On the other hand the blue and red components result definitely narrower than such a limit. Therefore they have tô be generated in times longer than the main laser pulse, namely also during the arrival of its pedestal on the target.

Finally we observe that, in the conditions of the present experiment the radiation transmitted through the target interacts with the plasma less strongly than the reflected one. In the spectrum of the reflected radiation the unperturbed component as well as the up and down component are still recognisable, but more structured and immersed in a wider background spectrum. The wide spectrum can be attributed to SPM, but in this case, in contrast with the transmission spectrum, the cut-off due to the critical density is absent.

In conclusion, the interaction of high intensity femtosecond laser pulses with very thin plastic targets has been investigated experimentally. The spectral properties of the transmitted light provide valuable information on the plasma formation and evolution. The spectral broadening of the reflected laser light reveals the high degree of coupling of such a radiation with the sharp boundary of the plasma.

REFERENCES

1. M. Pessot, P. Maine, G. Mourou, Opt. Comm., **62**, 419, (1987).
2. H.M. Milchberg, R.R. Freeman, Phys. Rev. A, **41**,2211, (1990).
3. C. Le Blanc, G. Grillon et al, Optics Letters, **18**, 140, (1993).
4. L.A. Gizzi, D. Giulietti, et al, preprint.
5. B. Corkum, Phys.Today, **48**, 36, (1995).