Hot electron suppression and optical studies in the intense circularly polarized femtosecond laser and foil target interaction

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New phenomena and applications continued to emerge in the relativistic femtosecond laser and plasma interaction study during the past decade. The thin and ultrathin foils were widely used for the laser ion acceleration[1-3] and the electron acceleration[4]. The laser prepulse may greatly modify the condition of the preformed plasma and lead to different results in the experiments for the same main laser pulse[5]. We have characterized the preformed plasma for ultrathin foil laser interaction via the transmittivity and the spectra study. Both overdense and underdense plasma were formed when main laser pulse arrived at the targets. These preformed plasmas were useful for the ion acceleration, the electron acceleration, or the new optical spectra production. We also observed the substantial hot electron suppression when a circularly polarized, near normal incident laser irradiated on a foil target, which has been predicted[6] and are very important for the radiation ion acceleration scheme.

1. LASER FACILITY DETAILS

The experiment was carried out on the SILEX-I laser facility in the Laser Fusion Research Center, CAEP. SILEX-I is a Ti:sapphire laser facility employing chirped-pulse-amplification (CPA) technique. The maximum output is 286 TW for a 30 fs pulse at 795 nm. A F/2.6 off axis parabola focused the 160 mm laser beam into a 10 μm spot (FWHM), in which about 25 percent of the laser energy was contained. The maximum intensity reached 6.8×10^{19} W/cm^2. The prepulse with contrast ratio of about 10^{-6} preceded the main pulse by a time between 0.5 ns and 3.5 ns.

2. TRANSMITTIVITY AND TRANSMITTED SPECTRA

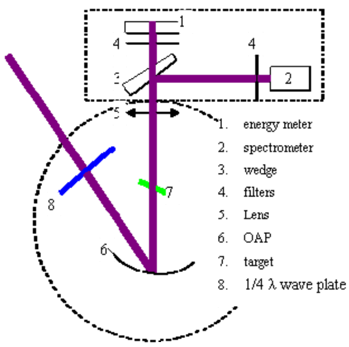

Fig. 1. The experimental setup for the measurement of the energy transmittivity and spectra of transmitted pulse.

Fig. 1 shows the experimental setup for the measurement of the energy transmittivity and the spectra of transmitted pulse for the laser penetrating through the ultrathin (150 nm ~ 190 nm) CH foils. A p-polarized laser was focused on the plane target with an incident angle of 24° . For some shots, a 2 mm thick liquid crystal quarter wave plate was installed to convert the p-polarized pulse into the circularly polarized pulse. The F/3 lens collected about forty percent of the transmitted light. The energy and spectra of transmitted pulse were measured by a calorimeter and a spectrometer (SpectraPro-500 or Ocean Optics HR 2000+), respectively. The transmittivity was obtained by careful calibration of all optical elements through the transmitted laser path and the use of a black box to shield all scattering light outside the target chamber.

Two identical optical diodes measured the prepulse of the compressed femtosecond laser pulse in the ns time scale for every shot in the experiment. Fig. 3 shows three typical cases in the experiment with different onset times of the prepulse for the similar laser intensity of $3 \pm 1\times10^{19}$ W/cm^2. The femtosecond laser light incident on the diode measuring the main pulse was attenuated by a factor of 10^6 (curve 2). The on-line measurement of the prepulse was crucial in the experiment because the conditions of the preformed plasma were greatly affected by the prepulse level and resulted in a very different main femtosecond pulse plasma interaction.

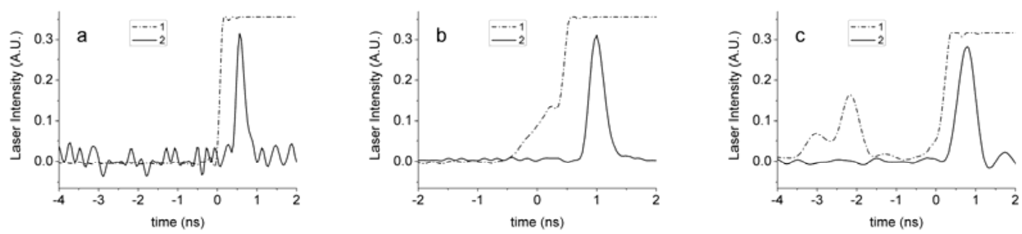

Fig. 2. The prepulse measured by two identical optical diodes in ns time scale. The onset times of the prepulse were 0.5 ns (a), 1.5 ns (b), and 3.7 ns (c), respectively.

The measured transmittivity (Tr) were quite different for three cases showed in fig. 2. Before the experiment of the laser ultra-thin foil interaction, the scattering light inside the target chamber originated from the target front surface and collected by the calorimeter 1 was measured to be less than 0.2 percent of incident laser. For the experiments (both p-polarized and circularly-polarized pulse) with similar prepulse as in the case a, the Trs fluctuated between 0.5% and 2.5%. However, the maximum transmittivity reached to 70% for case b, and 25 % for case c. The spectra of the transmitted pulse are shown in fig. 3 a-c corresponding to fig. 2 a-c. For the shortest onset time of the prepulse in fig. 3 a, both second harmonic and three halves harmonic emission were observed. With the onset time of the prepulse increasing to 1.5 ns as in fig. 3 b, the three halves harmonic disappeared. The second harmonics with ~ 6 nm red shift, as well as a new line at 640 nm, were observed. For the longest onset time of the prepulse in fig. 3 c, the broadening supercontinuum spectra extended from 280 nm to 940 nm were observed.

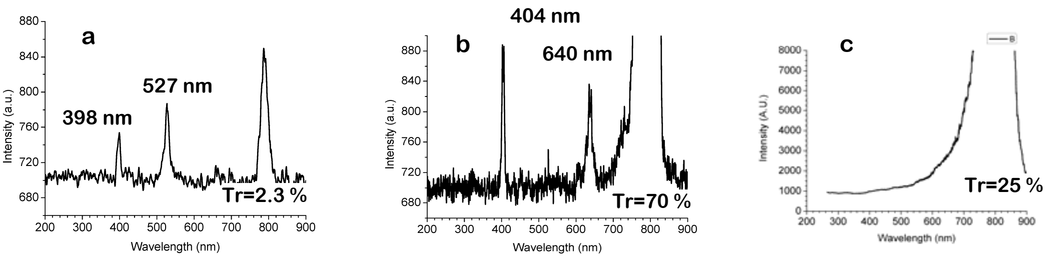

Fig. 3. The spectra of the transmitted pulse measured in the same three shots corresponding to those in fig. 2 a-c. Trs are the measured transmittivity.

The prepulse intensity (3×10^{13} W/cm^2) already exceeded the plasma formation threshold for the CH plastic[7]. The significant transmittivity for case b and case c was not the results of the anomalous transparent reported in the literature[8], but the results of the explosive expansion of ultrathin foil under the irradiation of prepulse and the formation of large scale underdense plasma. The 640 nm line in the fig. 3 b was most likely the forward stimulated Raman scattering, which indicated the peak density of preformed plasma was below the critical density when the main femtosecond laser arrived the target. This kind of preformed plasma was studied before for the laser wake field electron acceleration, the similar second harmonic emission with red shift was reported[9]. The supercontinuum spectra in the fig. 3 c were reported for the intense femtosecond laser pulse focused in the air[10]. We provided a new method to generate the supercontinuum with the explosive foil with the prepulse of the laser. The low transmittivity in fig 3.a suggested the existing of the overdense plasma layer. The transmitted laser energy before the plasma formation was estimated to be only a few mJ, which could not explain a few tens of mJ transmitted laser energy. Because the initial foil was only ~ 200 nm thick, the overdense plasma layer was also quite thin, some other mechanism, such as self-induced transparency and hole boring, may contributed to the observed relatively large transmitted energy. The origin of observed second harmonic and three halves harmonic emission were suggested from the rear side of foil, which indicated the scale length at quarter critical density in the rear side of the foil was larger than the laser wavelength[11]. To further understand the experimental results, the simulation with 1-D hydrodynamic code (MULTI) was performed. A 800 nm laser pulse irradiated on the 190 nm carbon with the intensity increasing linearly from 1×10^{12} W/cm^2 to the 1×10^{13} W/cm^2 within 600 ps. The plasma densities at three times were shown in fig. 4. The preplasma evolved from the initial overdense plasma to the symmetric underdense plasma, which supported the observed the transmittivity and the spectra.

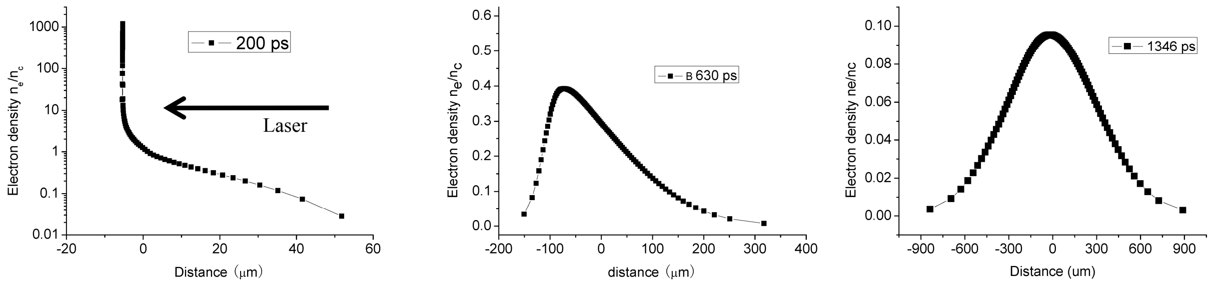

Fig. 4. The plasma density at different time points from the simulation with 1-D hydrodynamic code MULTI..

3. SUPPRESSION OF THE HOT ELECTRONS

In the hot electron emission study, the strong influence of laser incident angle and polarization was observed. As shown in fig. 5, for the 17-μm-thick copper foil targets, the hot electrons from target rear side were suppressed by a factor of ten with a near normal incident, circularly polarized laser compared to an oblique incident (24°), p-polarized laser. The large decrease of the emitted hot electron number was due to the suppression of both

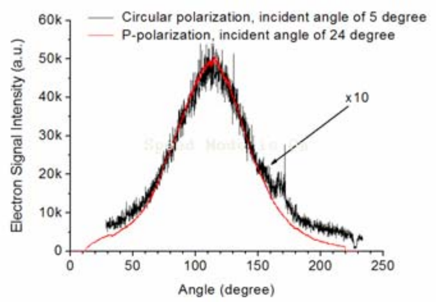

Fig. 5. The comparison of the emission of the hot electrons from the target rear side for two different laser irradiation conditions.

resonant absorption and ponderomotive heating for the normal incident, circularly polarized laser. This suppression is the requisite of the realization of mono-energetic ions in the radiation acceleration scheme[6].

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