Complex characterization of hot electron emission from laser produced plasma on thin foil targets

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Abstract

The investigation of laser interaction with thin foil metal targets was carried out at Prague Asterix Laser System (PALS). The iodine laser system PALS is capable of delivering energy up to 600 J at wavelength 1.315 μm to generate the plasma by focusing the energy at the target reaching the intensity up to 10^{16} $\mathrm{W \cdot cm^2}$. The hot electron distribution was measured using angular array of electron spectrometers to obtain angularly resolved distribution of hot electron temperature. The spontaneous magnetic fields generated in laser plasma were measured with complex interferometry using the synchronized femtosecond titanium-sapphire laser system. The characterization of the bremsstrahlung radiation along the laser beam axis was done using the scintillator stack diagnostic and evaluated using Monte Carlo simulation of particle transport.

The target parametric study was carried out to characterize the hot electron emission from the laser produced plasma for the tin targets with respect to target thickness and the energy of the main laser beam. Several other target materials were also investigated. The magnetic field distribution is shown for the target parameters in this study. Comparison with previous investigations is done to indicate further insight in the interaction of laser with plasma as well as the comparison with known scaling laws for hot electron temperature. The results of this experiment have further application for radiation sources and generation of accelerated particles.

Introduction

The interaction of laser radiation with solid targets at intensities above 10^{11} $\mathrm{W \cdot cm^{-2}}$ leads to ionization and creation of plasma on the surface of the solid target. With higher intensities above 10^{15} W $\cdot$ cm^{-2} can give rise to non-linear wave interaction such as two-plasmon decay or stimulated Raman scattering, which are responsible for hot electron generation. The energy distribution of these hot electrons can be estimated by known scaling laws [1]. At PALS laser facility, the two-plasmon decay and stimulated Raman scattering were investigated in detail by Cristoforetti et. al. [2].

The PALS laser is high power iodine laser system which can deliver on solid targets the intensities up to 10^{16} W $\cdot$ cm^2 in laser pulses with energies up to 700 J in duration 350 ps FWHM at wavelength 1315 nm. The results presented in this publication are from experimental campaign, where the interaction with thin metal foils with focused iodine laser beam was investigated. The targets used were tin foils with thicknesses of 6 μm, 25 μm and 50 μm. No phase plate was used ensuring the intensity in the focus in the range of 10^{16} W $\cdot$ cm^{-2}.

The experimental arrangement is shown on figure 1. The electron spectrometers were arranged at angles ($-48°$, $-37°$, $-22°$, $0°$, $20°$, $37°$, $48°$, $153°$, $163°$, $197°$, $207°$) at horizontal plane. The position of laser axis is at angle 0°. In addition first prototype of the scintillator stack diagnostic was used to gain the information about the spectrum of the emitted x-rays from the laser produced plasma and was placed at angle 180°. It was developed by Agarwal et. al [8] and consists of 15 crystals of Ce:Lyso scintillators. The light emitted from crystals was recorded by full frame camera with 50 mm lens at distance of 30 cm. The complex interferometry diagnostic was used to determine the plasma scale length and the electron density. This diagnostic was developed by Pisarczyk et. al. [3].

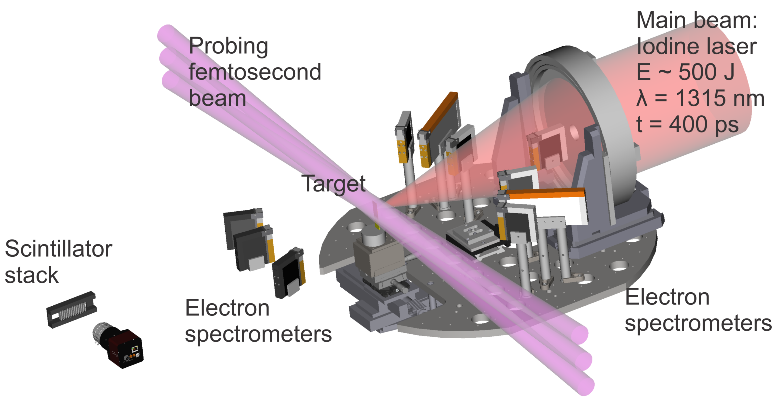
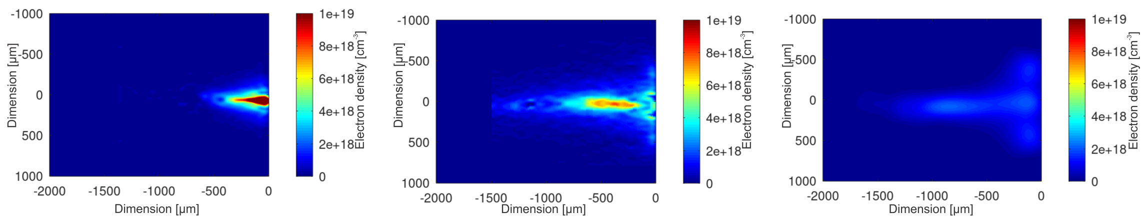


Figure 1: Outline of the experiment and positions of the electron spectrometers, scintillator stack and the probing femtosecond beam.

Experimental results

The results of complex interferometry for shot 58012 are shown in figure 2, where the evolution of plasma jet can be apparent. The observed plasma evolution in time is consistent with previous observations [6].



(a) −900 ps (b) −600 ps (c) 300 ps

Figure 2: Electron density of laser produced plasma for the shot 58012 at tin target with thickness 50 μm at delays in subcaptions with respect to the peak of laser pulse. Laser energy was 544 J.

The hot electron emission dependence on the laser pulse energy is given in figures 3 and 4. The similar threshold effect as it was observed before and reported in papers [4] and [5] is also apparent around the energy of 150 J otherwise the dependence of hot electron temperature is on the investigated interval of the energy linear in the same way as in previous experiments. The scintillator stack response is shown in figure 5. In this figure similar dependence of the response of the scintillators is apparent. The typical temperature of the energy distribution of hard x-ray detected by the scintillator stack is given in figure 6. The numerical unfolding of the energy distribution of X-rays using this diagnostic is outlined in paper by Istokskaia et. al. [9] [10]. The overall temperature of exponential distribution for the shots on tin targets was (65 ± 12) keV. Since the scintillator stack diagnostic is developed for higher energies of X-rays, the observed and unfolded temperature of the distribution is on the edge of sensitivity and further refinement is needed. For electron spectrometers and scintillator stack, the difference between target thickness was not observed in this experiment, which also needs to be further investigated in detail.

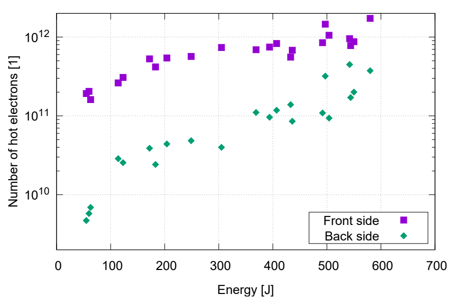


Figure 3: Dependence of the total emitted number of hot electrons on laser pulse energy.

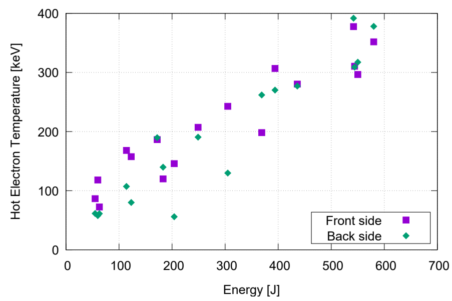


Figure 4: Dependence of the hot electron temperature on laser pulse energy.

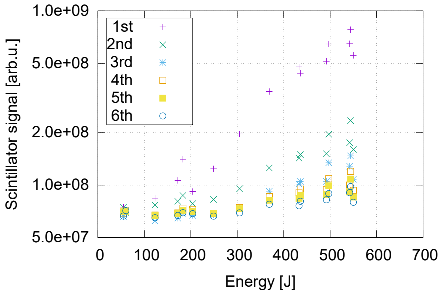


Figure 5: Dependence of the light output from each scintillator in scintillator stack. First 6 scintillators shown only.

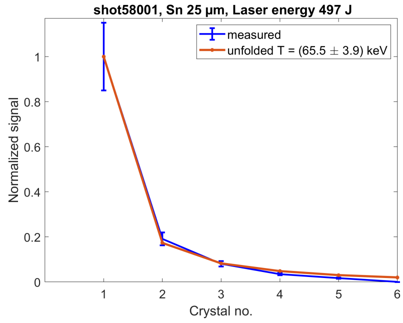


Figure 6: Unfolded energy fit to the scintillator exposures.

Conclusion

We have observed the electron density evolution of laser produced plasma on tin foil targets showing the jet-like expansion. We have observed the energy dependence of the hot electron emission from laser produced plasmas on thin tin foil targets. Given the values of hot electron temperature, detailed investigation into energy distribution in focus of the laser beam is required. The observation of scintillator stack show the potential in radiography as well as use of this diagnostic in high repetition experiments. However due to the nature of the experimental results, further detailed parametric investigation is required, as well as the detailed characterization of the energy distribution in the focal spot of the laser at high power.

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