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Observation of UV Harmonics from a Thin-Foil Target in the High-Intensity Laser-Driven Proton Generation

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We measure the UV harmonics from a thin-foil target by changing the laser pulse duration in the high-energy proton generation. The maximum proton energies are around 1 MeV. In the case of the ~500 fs, the peaks of UV harmonics up to fourth-order clearly appear. The spectra are broadened and shifted due to the laser and plasma interaction such as nonlinear and ponderomotive effects at the pulse durations of ~100 fs and 30 fs.

Keywords: High-intensity laser, thin-foil target, plasma, proton, harmonics

1. Introduction

In the high-intensity laser interactions with thin-foil targets the high-energy particles, hard x-ray and high-order harmonics are produced [1-6]. High-energy protons have been observed at the rear side of the thin-foil target [7,8]. The high-order harmonics generated from the solid surface in the direction of the specular reflection are observed by reducing the preformed plasma at the front side of the target. [9-12].

The laser and thin-foil interaction can generate the high-energy proton at the rear side and harmonics at the front side simultaneously [13]. The harmonics provide a useful tool for diagnostic the high-density plasmas such as electron density or magnetic field [14-18]. Descamps et al. have demonstrated the extreme ultraviolet interferometry by using the high-order harmonics as a probe beam [14]. Tatarakis et al. and Wagner et al. have used the reflected harmonics for the measurements of magnetic field [16,17].

In our experiment, we observe the UV harmonics up to fourth-order simultaneously with the protons with a 1.5 μm-thick Polyethylene terephthalate (PET) with Al coated target irradiated with a high-intensity Ti:sapphire laser by changing the laser pulse parameters.

2. Experimental setup

We use a Ti:sapphire laser system (J-KAREN) at JAEA [19]. The laser has the central wavelength of ~800 nm with the pulse duration of 30 fs [full width at half maximum (FWHM)]. The contrast ratio of the ASE is less than 10^{-8}. Figure 1 shows the schematic view of the experimental setup. A p-polarized laser beam is focused by an off-axis parabolic mirror with a focal length of f = 152.4 mm and an incidence angle of 45˚. The spot size of the focused laser beam is 4 μm (FWHM) x 3 μm (FWHM). It contains the ~64 % of energy within $1/e^2$ from the profile of the focusing pattern. The estimated peak intensity is up to 10^{20} W/cm^2 with the energy of ~1 J. A tape target driver provides a fresh surface of the 1.5 μm thick PET target with Al coating (30 nm).

The protons are observed with a time-of-flight (TOF) ion energy analyzer [20,21]. The protons produced by the intense laser are measured in the direction normal to the target. The TOF proton measurement gives an on-line real time information of proton energy distribution.

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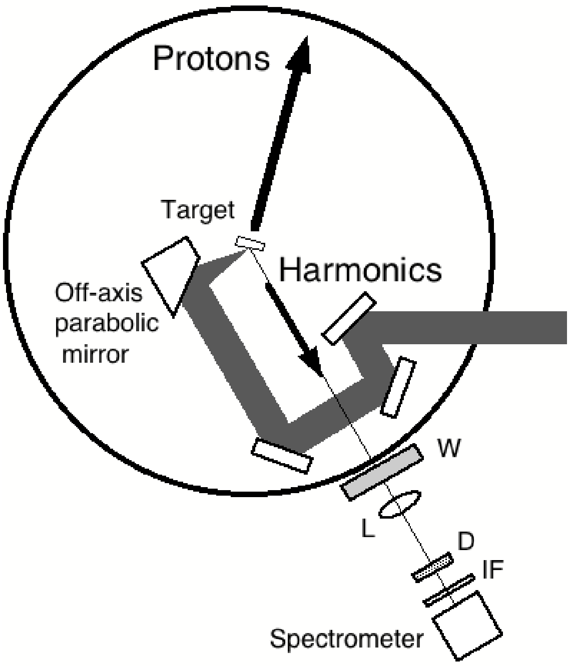

Fig.1 Schematic of the experimental setup: L corresponds to the fused silica lens (focal length of 300 mm), W to the fused silica window, IF to the narrow-band interference filter (Acton Research; 200-W-2D), D to the light shaping diffuser (fused silica).

A fiber spectrometer with the spectral range from 190 nm to 515 nm (Ocean Optics: USB2000) is placed at the reflection direction as shown in Fig. 1. The fused silica lens (focal length of 300 mm) is used for imaging the harmonic emission directly to the entrance slit of the spectrometer without the fiber. The harmonics pass through the fused silica window and the light shaping diffuser (fused silica). The narrow-band interference filter (Acton Research; 200-W-2D) is placed in front of the spectrometer to reduce the fundamental laser beam and second- and third- order harmonics. The relative intensity of measured spectrum is calibrated by Deuterium lamp (Hamamatsu). The calibration includes the spectrometer, window, diffuser, and interference filter.

3. Experimental Results

Figure 2 shows the proton energy distributions obtained by TOF for the laser pulse duration of 30 fs. The protons are generated with a maximum energy of ~1.1 MeV. The dependence of proton generation on laser pulse duration is measured by varying the distance of the gratings in the pulse compressor with negative chirp. The peak laser intensities are ~1x10^{20} W/cm^2, ~3x10^{19} W/cm^2, and ~6x10^{18} W/cm^2 for the pulse durations of 30 fs, ~100 fs, and ~500 fs. The maximum energies of protons are ~1.1 MeV, ~1.1 MeV, and ~0.8 MeV for the pulse durations of 30 fs, ~100fs, and ~500 fs, respectively.

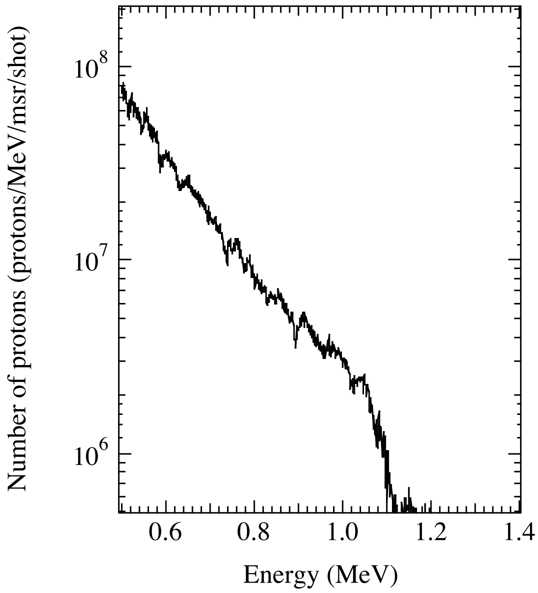

Fig.2 The energy distributions of protons measured by TOF spectrometer at the pulse duration of 30 fs.

We observe the UV harmonics and proton signal simultaneously. Figure 3 shows the spectra at the pulse durations of (a) 30 fs, (b) ~100 fs, and (c) ~500 fs. The broad spectrum appears at the pulse duration of 30 fs and ~100 fs. The UV harmonics up to fourth-order clearly appears when the pulse duration is ~500 fs. The peaks of the third- and fourth- harmonics are broadened and shifted to the long wavelength side as the laser intensity increases.

4. Discussion

We assume that the high-order harmonics are generated in the vicinity of the critical density region where the electron density distribution is highly inhomogeneus. Possible interpretation of harmonic generation is given by the oscillating-mirror model [3,22], coherent wake emission [10,23]. Under our experiment conditions, the ASE effects can result in the formation of a relatively low-density plasma in front of the target, which prevents propagation of the laser pulse into the overcritical region. In this case the “oscillating mirror” corresponds to the oscillations of the critical surface in the plasma resonance region, as it is discussed in Ref. [24].

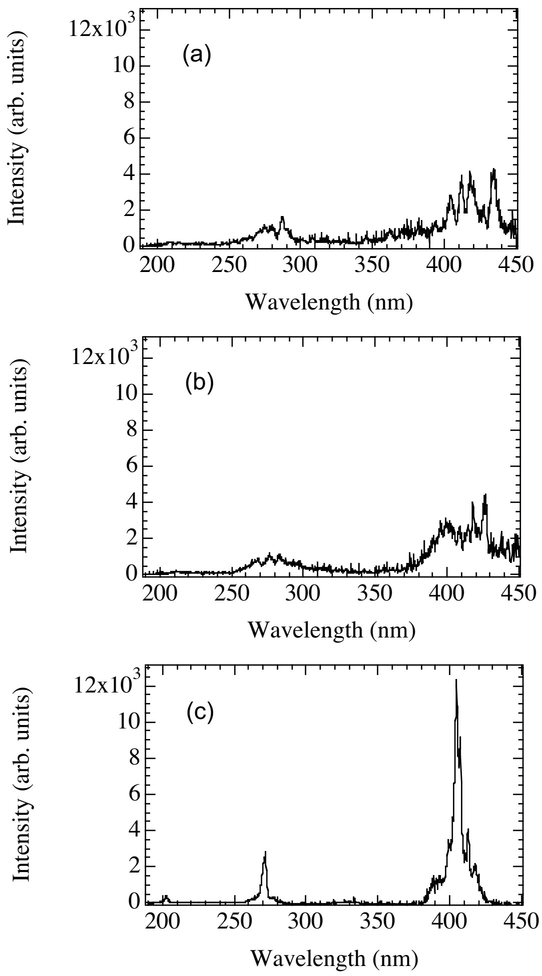

Fig.3 Visible spectra at the pulse durations of (a) 30 fs, (b) ~100 fs, and (c) ~500 fs. Corrected for sensitivity of spectrometer, window, diffuser, and interference filter.

The red shift of the harmonic spectra can be found when the laser intensity increases. It may be caused by Doppler shift at the critical density surface [25-28]. The strong ponderomotive force of the main laser pulse pushes the critical density of expanding preformed plasma [29]. The critical density of the 800 nm wavelength is $1.7x10^{21}$ cm^{-3}. The velocity of the critical density surface is estimated as $\sim 4x10^{8}$ cm/s at the spectrum shift of 5 nm for third-order harmonics. The broadening of the UV spectra can be attributed to the relativistic self-phase modulation of the incident laser as it propagates through the preformed plasma [30-32]. This will be described in more details elsewhere.

The spectral shift and broadening show that preformed plasma is generated at the front side of target. The preformed plasma affects absorption and in particular high-energy proton generation.

5. Summary

We measure the UV harmonics by changing the laser pulse durations of 30 fs, ~100 fs, and ~500 fs in the laser-driven proton acceleration. The maximum proton energies are around 1 MeV for these pulse durations. In the case of ~500 fs, the peaks of UV harmonics up to fourth-order are clearly appeared. The spectra are broadened and shifted by the laser and plasma interactions such as nonlinear and ponderomotive effects at the pulse durations of ~100 fs and 30 fs. The spectra shift and broadening show the preformed plasma generation at the front side of target. The harmonics observation provides a useful tool for diagnostics of the high-intensity laser and plasma interactions.

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