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Laser light reflection by the nonlinear plasma wave formed in laser-plasma
レーザープラズマ中に生成される非線形プラズマ波によるレーザー光の反射

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The relativistic flying mirror concept has several interesting features for generating short wavelength, coherent, ultrashort electromagnetic radiation. The experiment of the flying mirror was conducted in a head-on collision setup. Initially 800 nm laser pulses were converted to the extreme ultraviolet region (several tens of nm). The source size of the radiation was characterized to 7.1 μm with an imaging system composed of a spherical mirror and CCD.

1. Introduction

When an intense, ultrashort laser pulse is focused onto a tenuous plasma a Langmuir wave is excited behind the laser pulse [1]. The wave is also known as a laser wake wave and the static electric field of the wake is useful for electron acceleration because of its high field gradient being tens or hundreds of GV/m. The wake wave can break when the drive laser intensity is high. At this moment, the electron velocity is equal to the phase velocity of the wake. The electrons have a cusp form, which is a thin layer and move coherently, thus the electrons can act as a partially reflecting mirror moving nearly at the speed of light. This is the proposed concept of the relativistic flying mirror by Bulanov et al. [2]. So far some of the features of the flying mirror have been confirmed experimentally. The reflection and the frequency upshift were demonstrated in a counter-crossing configuration [3,4], and the reflectivity was estimated to be in good agreement with theory [5]. However, characterizing the pulse duration and coherence of the reflected pulse and testing the focusability or the source size of the flying mirror still remain as experimental challenges.

Here we report our recent experimental results and implementation to observe the focused spatial size using an imaging system.

2. Experiment

Three laser beams, driver, source, and probe beams, were split from the output of the J-KAREN laser before entering the pulse compressor. The central wavelength was 800 nm. The driver and probe lines had delay lines to control the arrival times at the interaction point. The driver beam was used to excite nonlinear plasma waves and had an energy of 400 mJ and a pulse duration of 30 fs (FWHM). The driver beams were focused onto a He gas-jet target with an off-axis parabola (OAP) whose focal length was 475 mm. The source beam had the energy of ~400 mJ and the pulse duration was varied from 30 to ~100 fs by inserting a glass block (Fused silica). The source beam was focused onto the gas target in a head-on collision manner with an OAP with the focal length of 775 mm. The 4-sigma spot diameters of the driver and source were 30 μm and 45-50 μm, respectively. The gas jet target was provided with a pulsed valve through a conical nozzle whose exit diameter was 1 mm in diameter. The gas density was calibrated using a Mach-Zehnder interferometer and the plasma density used in the experiment was $\sim 10^{19}$ cm^{-3}. The probe beam was introduced perpendicularly to the driver and source axis to diagnose the propagation of both pulses in the plasma (shadowgraphy and interferomety).

In order to align the driver and source beams to collide in the plasma we employed several techniques. In addition to methods reported in Ref. [6], we have also implemented a new method to check the horizontal and vertical alignment of the two pulses.

In order to detect the reflected pulses, we used two imaging spectrographs in the forward (0°, driver propagation axis) and at 13±7°. The former was a grazing incidence flat-field spectrograph and the latter was composed of a spherical mirror with an aperiodic multilayer coating, a transmission grating, optical blocking filters and a back-illuminated CCD. When we removed the transmission grating, the detector worked as an imaging device with the magnification of ~5. In addition, 10-fold spatial resolution improvement was achieved if we replace the CCD with a LiF crystal [7].

3. Results and Discussion

When the two beams were aligned carefully so as to overlap both in space and time, we have observed reflected signals in both spectrographs. A typical spectrum obtained in the forward direction is shown in Fig. 1. As expected, the initial photon energy 1.55 eV is upshifted to 65 eV having a quasi-monoenergetic feature. The structure of the reflected pulse is qualitatively reproduced with a high resolution numerical simulation. The quantitative analysis is now underway.

In the 13±7° direction, the reflected pulse was also observed as shown in Fig. 2. The source size in the vertical space was 7.1 μm, which is smaller than the previously measured value (16μm). We also tested the spatial resolution using a LiF detector, which indicates a spatial resolution of 2 μm. This test was done with another X-ray source using relativistic high-order harmonics [8]. The preliminary analysis implies that the source size is smaller than 1 μm.

5. Conclusions

We have conducted the relativistic flying mirror experiment using J-KAREN in the head-on setup. The quasi-monoenergetic structures of the reflected pulses have been confirmed. The spatial resolution of the reflected radiation was 7.1 μm, which is limited by the spatial resolution of the detector.

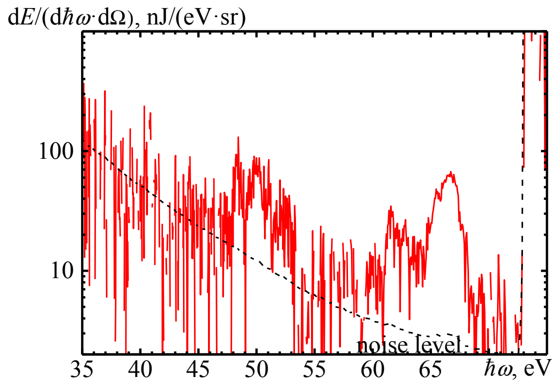

Fig.1. The reflected laser spectrum detected in the forward direction.

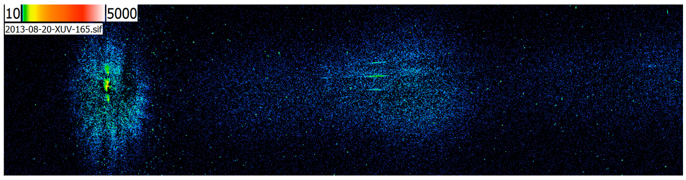

Fig.2. A raw image of the reflected laser spectrum detected in the 13±7° direction. The left part shows the zero order diffraction and the middle part shows the 1st order diffraction. Horizontal and vertical axes correspond to the wavelength and the vertical size, respectively.

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