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Ultra-short X-ray and electron generation via laser-plasma interaction
レーザープラズマ相互作用による超短パルスX線及び電子ビーム生成

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Ultra-short quantum beams can be generated by laser-plasma interaction. Ultra-short X-ray pulses and electron beams are generated via flying mirror and laser-acceleration. Laser light reflection by a relativistically moving electron density modulation (flying mirror) in a wake wave is investigated. A counter- propagating laser pulse is reflected and upshifted in frequency with a multiplication factor of 37–66, corresponding to the extreme ultraviolet wavelength. A laser pulse oscillates a laser-accelerated electron beam in the laser field. From electron oscillations in the image of the electron energy distribution, the electron beam pulse width is estimated to be 1.7 fs (rms).

1. Introduction

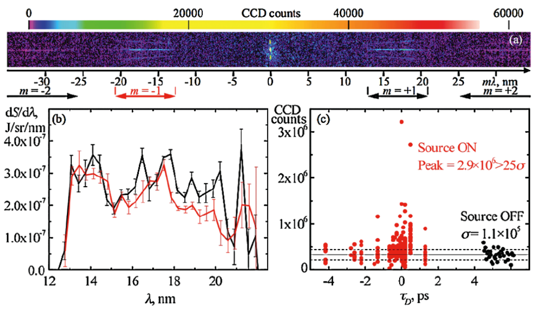
Short, coherent x-ray pulses are important tools for applications [1]. Reflection from flying mirror [2,3] is one of the schemes to generate ultrashort pulses. The flying mirror is dense electron shells formed in a breaking wake wave, excited by the intense, short pulse laser in underdense plasma. These shells partially reflect a counterpropagating laser pulse. The reflected pulse inherits properties of the incident electromagnetic wave, such as coherence, polarization, and pulse form. The reflected radiation wavelength is shortened due to the double Doppler effect.

Laser-acceleration [4] has the possibility to generate an ultrashort electron beam [5] with high quality [6–9]. In applications of the electron beam, it is necessary to characterize the electron beam. When the pulse length of the electron beam is shorter than the plasma wavelength and the electron beam is in the laser pulse, by using electron oscillation, the energy spectrum is converted to the pulse width of the electron beam by the laser field.

In this paper, we present the result of the flying mirror experiment in a configuration with the head-on collision of two laser pulses, and the result of the pulse width measurement of the laser-accelerated electron beam.

2. Flying mirror

The experiment was performed with a Ti:sapphire laser named J-KAREN [10]. The laser pulses were split after the compression into driver (to excite the wakefield) and source (to be reflected) pulses. The typical energies of the driver and source pulses were 400 and 42 mJ. Pulse durations of the driver and source pulses were 27 and 34 fs. The laser pulses were focused onto a helium gas-jet. The laser pulses were set to collide head on. The estimated peak irradiances in vacuum were 6.5×10^{18} W/cm^2 and 1.2×10^{17} W/cm^2 for the driver and source. The maximum plasma density was 4.7×10^{19} cm^{-3}. The reflected light was resolved by a



Fig,1 (a) Raw CCD image. (b) Spectra in the diffraction order of m=1 and m=-1. (c) CCD counts within the 1st diffraction order.

normal incidence spectrograph (NIS). The NIS covered the observation angles α from 9° to 17°. The imaging magnification was 2.37.

The observed signal in the NIS is shown in Fig. 1. In the raw image of the CCD shown in Fig. 1(a). The similarity of the spectra of m=1 and m=-1 shown in Fig. 1(b) confirms that the detected signal was resolved by the transmission grating, and was not from high energy photons due to bremsstrahlung by fast electrons. From the observed spectrum, we determine the range of γ_{ph} in the actual shot. In order to obtain the same wavelength range of 12.8–22.0 nm in the observation angles of α=9°–17°, the γ_{ph} should be in the range of 5–7. The factor γ_{ph} can also be estimated from the simplified relationship $\gamma_{ph} \sim (n_{cr}/n_e)^{1/2}$, where n_{cr} and ne are the critical density and the plasma density. If we use the measured density, $(n_{cr}/n_e)^{1/2} \sim 10$. Because this produces a rough estimate of γ_{ph}, this estimation is in accordance with the measurements.

3. Pulse width of laser-accelerated electron beam

The experiments have been performed with a Ti:sapphire laser named JLITE-X [11]. The laser pulse with 130 mJ energy was focused onto a 3-mm-diameter Nitrogen gas jet. The pulse duration was 40 fs. The peak irradiance in vacuum was 7.3×10^{17} W/cm^2. The electron energy is measured with a magnetic spectrometer composed of a dipole magnet, a scintillating screen, and a CCD camera.

A quasi-monoenergetic electron beam is generated in the self-injection scheme by using a Nitrogen gas target around the plasma density, n_e, of 4.0×10^{19} cm^{-3} assuming 5 ionizations of N_2. The electron beam oscillates in the electric field of the laser pulse. In energy space, when the electron beam is in the acceleration or deceleration phase, the electron oscillation can be observed and the electron energy spectrum can be converted to the electron pulse width. We can measure the pulse width by measuring the energy spectrum.

Figure 2 shows the typical image of an energy distribution at $n_e = 4.4\times10^{19}$ cm^{-3} when the laser pulse has S (vertical) -polarization. The oscillation has an angle of 16 mrad. When the laser pulse has P-polarization, the image of the energy distribution has no oscillation, because the direction of the laser field oscillation is parallel to the energy axis. The wave structure of the energy spectrum depends on the laser frequency. The pulse width (FWHM) of the electron is 1.5-cycles at a wavelength of 800 nm. The pulse width is 1.7 fs (rms).

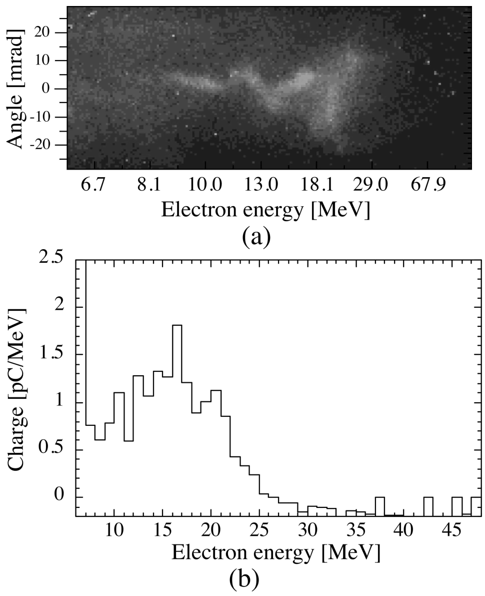


Fig.2 (a) Typical image of an electron beam in energy space and (b) a projection of the image onto the energy axis at n_e=4.4×10^{19} cm^{-3}.

4. Conclusions

We have conducted a laser light reflection experiment from a wake wave. With and without the source, there is deference clearly. The flying mirror signal is observed in the NIS. Stable and monoenergetic electron beams have been generated by using a Nitrogen target. In the image of the energy spectrum, the electron oscillation by the laser field is observed. The energy spectrum can be converted to the electron pulse width. The result indicates a 1.7 fs (rms) pulse width for the electron beam.

Acknowledgments

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