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Femtosecond electron deflectometry to measure the emission time of the laser-produced fast electrons from a solid target

フェムト秒電子偏向法によるレーザー生成高速電子の固体ターゲットからの放出時間測定

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The emission duration of fast electrons from the surface of solid target irradiated by a laser pulse, i.e., the pulse duration of fast electrons, was investigated by using femtosecond electron deflectometry, for the laser pulse durations of 200fs, 400fs, 540fs, and 690fs. We have found that the emission duration depends on the duration of the incident laser pulse. It is indicated from numerical calculations of 3D charged particle dynamics that the emission duration of fast electrons is almost equal to the duration of laser pulse.

1. Introduction

The generation and transport of fast electrons during interaction between intense femtosecond laser and solid target are key issues for the development of attractive applications such as fast ignition for inertial confinement fusion [1], particle acceleration [2], ultrashort electron pulse generation [3], and high-quality X-ray production [4]. Recently, in order to illustrate the collective behavior of fast electrons immediately after femtosecond laser is irradiated, the dynamics of the fast electrons have been measured directly by using a laser accelerated proton beam with high temporal resolution of a few picoseconds [5]. This technique, however, cannot achieve the temporal resolution of femtosecond order because of the duration of proton beams, so that it is not sufficient to observe the motion of fast electrons that is emitted from laser plasma. The emission time of fast electrons has not been observed during and immediately after laser pulse irradiation.

In this paper, we present the behavior of fast electrons emitted immediately after laser pulse, measured by using femtosecond electron deflectometry. By changing the durations of the incident laser pulses from 200 fs to 690fs, the emission duration of electrons was varied. By comparing experimental results and the numerical calculations, it is indicated that the emission time was almost equal to the duration of laser pulse.

2. Experimental Setup

The the experimental setup for femtosecond electron deflectometry is described in Ref. [6]. A laser pulse from a Ti:sapphire chirped-pulse amplification system is divided into two half pulses (in Fig. 1 in Ref. [6], an upper pulse and a lower pulse). The time delay between two pulses was controlled with an actuator. These divided two pulses were focused on to a solid target (Al foil of 12μm thickness) at an incident angle of 45° by using an *F*/3 off-axis parabolic mirror. The distance between two focal positions was 27±1 μm. The position of the target surface was carefully measured with a laser displacement sensor and precisely adjusted, so that the position displacements of the target surface from the laser focal positions were less than ±3 μm. The laser pulse duration was varied between 200 fs and 690 fs by controlling the distance of the two gratings of the compressor. The laser pulse energy was controlled in order that the intensity of each pulse on the target was 1×10^{16} W/cm^2.

The two laser pulses produced two electron pulses emitted omnidirectionally. The electrons emitted in specular direction were collected and focused onto a fluorescent screen by an electron lens. The sensitivity of this imaging system was high enough for the electron source image to be obtained by only one laser shot [7]. The energy of electrons imaged on the screen was selected by the electron lens, and it was 120 keV.

When the time delay between the upper and lower laser pulses is small, the two electron pulses will be deflected by electromagnetic force (mainly Coulomb repulsive force) from each electron source, immediately after they are emitted from the target. This deflection is detected corresponding to the

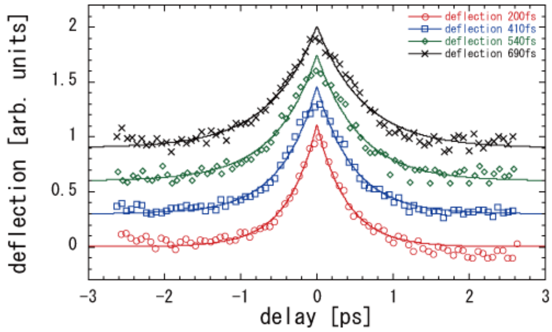

Fig. 1. The dependence of the deflection on the time delay between two laser pulses.

displacement of the distance of two electron sources imaged on the screen.

3. Results and Discussions

Figure 1 shows the dependence of the deflection on the time delay between the two laser pulses. Each shows the deflection at the laser pulse duration of 200 fs (circle), 410 fs (square), 540 fs (diamond), or 690 fs (cross). The deflection was normalized by each maximum value. Each point was obtained by averaging over of 30-50 laser shots. The solid lines in the Fig. 1 are fitted with exponential functions to evaluate the interaction times of two electron pulses. It was observed that the deflections decrease when the time delay between two laser pulses increases for any laser pulse durations. When the time delay was over ±2 ps, deflections were not observed. Figure 2 shows the dependence of the interaction time of the two electron pulses on the laser pulse duration. The interaction time is determined as the temporal interval given by half width of e^{-1} maximum of the function shown in Fig. 1. As shown in Fig. 2, as the laser pulse duration increases, the interaction time of the two electron pulses increases. This indicates that the emission duration of the electron pulses from the target surface (or laser plasma) correlate closely with laser pulse duration.

To support our results, we have calculated the strength and duration of the electromagnetic fields

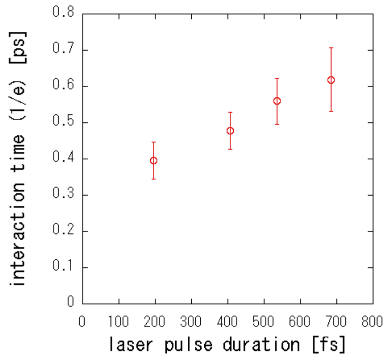

Fig. 2. The dependence of the electron pulse interaction duration of the laser pulse duration.

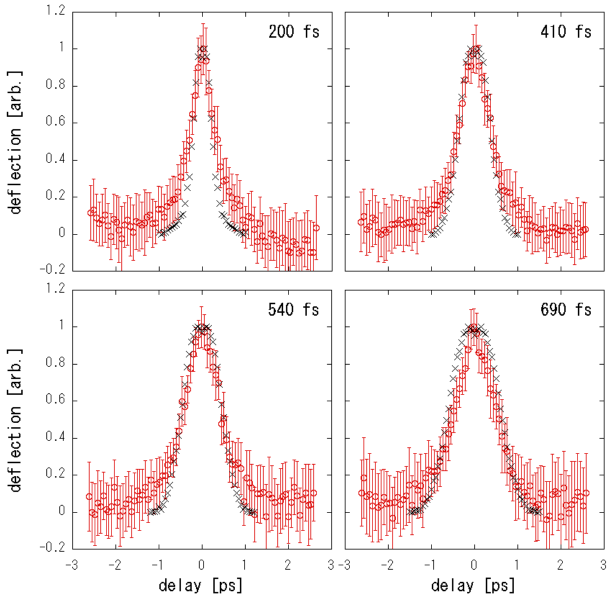

Fig. 3. Comparison between the deflections measured by femtosecond deflectometry (circle) and calculation (cross).

produced by electron pulses with GENERAL PARTICLE TRACER (GPT) code [8]. It is assumed that initial electron pulses emit isotropically, the temperature is 60 keV, and the total charge of one electron pulse is 0.3 nC. These initial states of electron pulses base on experimental results. The electron pulse duration is assumed as 200 fs, 410 fs, 540 fs, or 690 fs, corresponding to incident laser pulse durations respectively. Figures 3 shows the deflections obtained by experiment (circle) and calculation (cross) at each pulse duration. The error bars show the standard deviations of the experiments. The experimental results well agree with the numerical results, when the laser pulse duration is assumed to be equal to the electron pulse duration.

3. Summary

We have measured the emission times of fast electrons produced under femtosecond laser pulse irradiation by employing femtosecond electron deflectometry. With numerical calculations, it is indicated that the emission duration of fast electrons is equal to the duration of incident laser pulse.

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