Probing ultrafast motion of critical surface pushed by multi-pico-second relativistic radiation pressure

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INTRODUCTION

Relativistic electron (RE) acceleration by a high-intensity laser is an important to produce fusion plasma heating and TNSA proton acceleration etc. Dependence of RE kinetic energy distribution on laser intensity has been studied[1,2]. However, effects of pulse duration did not be taken into account in the previous works. A material and plasma are continuously irradiated by relativistic laser pulse over multi-pico-second in the recent kilojoule-class PW laser facilities such as LFEX in Japan, LMJ-PETAL in France, OMEGA-EP and NIF-ARC in US. We observed generation of super-ponderomotive relativistic electrons (SP-REs) in multi-ps laser-plasma interaction using ultra high contrast LFEX laser pulse in our previous experiment.

We clarified that self-generated static electric and magnetic fields are essential for the generation of SP-REs with the help of particle-in-cell (PIC) simulations. In the first stage, SP-RE are generated by a combination of a laser field and a quasi-static self-generated electric field[3] in the acceleration region. In the second stage, the SP-RE energy is boosted furthermore by the loop-injected-direct-acceleration (LIDA) mechanism[4], where SP-REs are kicked back again to the acceleration region by a strong quasi-static Mega-Gauss magnetic field generated spontaneously at the critical surface. Amplification of the spontaneous magnetic field up to Mega-Gauss strength takes several picoseconds. We found in the PIC simulation that generation of spontaneous quasi-static magnetic fields synchronizes with the expansion of the critical surface heated by the continuous PW laser irradiation. This has not been recognized in the previous studies[5,6]. We have developed a model to describe the ultra-fast hydrodynamics of a PW laser-heated plasma[7]. In this research, we experimentally verify the following two numerical findings. (1) Sudden growth of spontaneous magnetic field growth. (2) Synchronization between the SP-RE generation timing and the plasma expansion timing. The measurements will be compared with the PIC and the model calculations.

LFEX laser pulses will be stacked temporally with arbitrary delays between the beams. In this study, a single beam (case A: 1.2 ps FWHM pulse duration and peak intensity of 2.5×10^{18} W/cm^2) and stacked beams (case B: 3.0 ps FWHM pulse envelope and peak intensity of 3.0×10^{18} W/cm^2) will be used. The energy distribution of REs emanated from the target to the vacuum was measured with an electron energy analyzer located 20.9° from the incident axis of the LFEX laser. Time evolution and spatial profile of the magnetic field will be observed by a time-gate camera with time-jitter-less 500 fs optical probe laser. Ultra-fast motion of laser-plasma interaction surface will be observed by Frequency-Resolved Optical Gating (FROG) technique.

POLARIZATION GATING FROG (PG-FROG)

The FROG with high temporal resolution and high wavelength resolution has been designed in the collaboration with Dr. G. E. Kemp of LLNL. In the FROG, a pulse is divided into a signal pulse (transmission) and a gate pulse (reflection) using a 70R/30T beam splitter. The signal pulse is incident into the Glan-Taylor polarizer. The first polarizer transmits only p-polarized component, and the transmitted pulse is focused into the nonlinear medium (NLM) using a cylindrical lens (f=70 mm). The gate pulse rotates the polarization of the signal pulse by the optical Kerr effect in the NLM. Birefringence is induced only when gate pulses are present. After re-collimating the signal pulse with a cylindrical lens (f=70 mm), the desired signal is separated using an analyzer. In our configuration, the extinction ratio is about 10^{-4} or more when Glan-Taylor polarizers pair has crossed arrangement. A cylindrical lens with 130 mm focal length relays an image on NLM to a camera with keeping temporal profile, while the autocorrelation signal is spectrally resolved by a holographic diffraction grating (reflective grating) with 1200 Grooves/mm and a cylindrical lens with 150 mm focal length.

LFEX EXPERIMENT

The first LFEX experiment was held last November. One LFEX beam delivered 230 J of 1.053 μm wavelength laser light with a 3.3 ps duration (FWHM). The spot diameter on a target was 30 μm of the full width at half maximum (FWHM), and about 60% of the laser energy was contained in this spot. The peak intensity of one beam was 3.9×1018 W/cm2. The contrast ratio of the LFEX laser pulse was 109 at 1.2 ns before the main pulse. The main beam was focused on an aluminum-coated optically polished BK7 glass by an f/10 off-axis parabolic mirror. A typical FROG signal was observed when a filter with an appropriate optical density was installed in the CCD camera (Fig. 4). From this signal, the pulse width was estimated to be 3.3 ps (FWHM), which agreed with the result of single shot autocorrelator. Moreover, the spectral width is estimated to be 1.6 nm (FWHM). This value indicates that spectrum narrowing occurs in the disk amplifier. (The spectral width is approximately 2 nm before passing through the disk amplifier.)

When we removed the neutral density filter of the CCD camera, a weak red shift component produced by plasma motion was observed. The most shifted component shifted about 7 nm from the center wavelength. This value strongly depends on the degree of ionization and the degree of ionization estimates about 7 to 8 from spectrum shift. This corresponds to the degree of ionization calculated by corresponding laser intensity for over-the-barrier ionization of aluminum.

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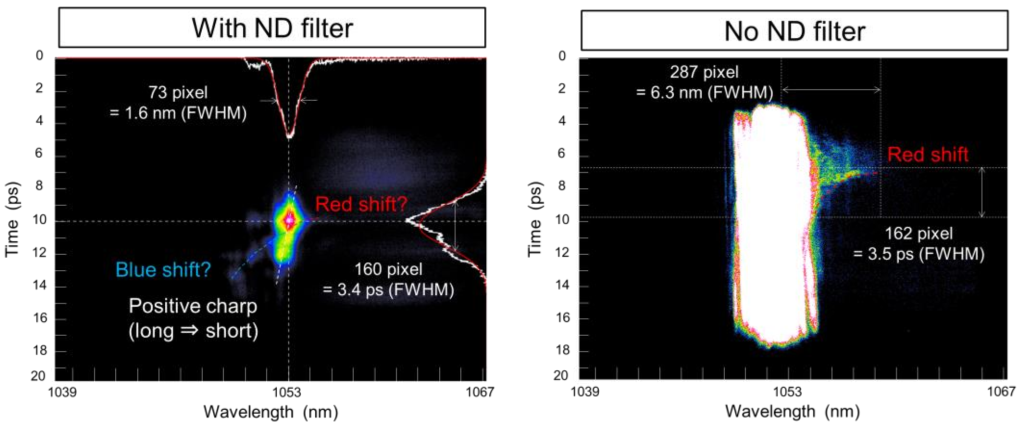

Figure 2 (Left) Typical FROG signal (Right) Red shift component