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Laser wakefield acceleration with axisymmetric polarized laser pulse
軸対称偏光レーザーパルスを用いたレーザー航跡場加速

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Axisymmetric polarized laser pulses can focus electrons into small area due to its transverse ponderomotive force because the spot of the laser pulse has donut shape. This feature can be useful for injection of large amount electrons into a wakefield excited by another laser pulse in staged laser wakefield acceleration. We present the experimental results of laser wakefield acceleration with using the axisymmetric polarized laser pulse.

1. Introduction

Laser-driven plasma acceleration of electrons has been evolved from a theory to a technology ready for applications in past a few decades. The huge field in plasma wake with ultrashort wavelength can not only accelerate the electron beam to high energy within short distance but also make ultrashort bunch with high charge, which can be available for many applications such as ultrafast electron imaging.

Axisymmetric polarized laser pulses (APP) have donut-shape focal spot. The transverse ponderomotive force of the APP can collect large number of electrons into the central limited area of the spot[1]. The increase of charge density of electron beam can be expected due to injecting this massive electrons to a wakefield excited by another laser pulse in staging acceleration. We have performed preliminary experiments of laser wakefield acceleration (LWFA) with using the APP.

2. Experimental setup

This experiment has been performed with a 40-TW Ti:Sapphire laser system (Amplitude Technologies) at Photon Pioneers Center, Osaka University based on a chirped pulse amplification(CPA) technique. The pulse energy on target was varied up to 460 mJ and the pulse duration was 30 or 50 fs. The central wavelength of the laser pulse is 800 nm. The contrast ratio between the main pulse and the nanosecond pre-pulse caused by the amplified spontaneous emission (ASE) is ~ 10^{10}. The maximum laser intensity of the APP on the target is estimated to be ~ 5 x 10^{18} W/cm^2.

A linear polarized laser pulse (LPP) with diameter of ~ 50 mm is converted to APP. beam by passing through an 8-divided waveplate[2,3]. As shown in Fig.1, the 8-divided waveplate is consisted from 8 pieces of 1/2 λ waveplate with different optical axis. The axisymmetric polarizations (radial, azimuth and spiral polarizations) can be changed by rotating the waveplate. The APP is focused on ~ 100 μm from the front edge of the slit nozzle by a gold-coated off-axis parabolic mirror with f/3.5. The length of gasjet is 1.2 mm length. The gas number density is estimated to be 1.1 ~ 3.4 x 10^{19} cm^{-3}. To stabilize the pointing and the profile of the beam using plasma micro optics, a magnetic device consisted of two ring-shaped neodymium magnets applies external static magnetic field (B ~ 0.25 T) in laser propagation direction[4-6].

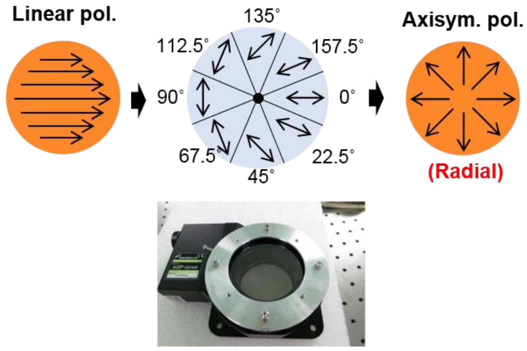

Fig.1. 8-divided 1/2λ waveplate

The spatial distribution of ejected electron beams is measured by a phosphor screen (Mitsubishi Chemical Co. LTD, DRZ-High with a CCD camera (Bitran Co., BU-51LN). An electron spectrometer measures the energy spectrum of the beams using dipole magnets. Shadowgraph imaging of the plasmas with probe pulse (400nm, ~ 50fs) and spectral measurement of side scattering from the plasma are also conducted.

3. Results and Discussion

The focal spot patterns with/without using the 8-divided waveplate on target measured by focal spot monitor are shown in Fig.2. The focal spot of the APP has clearly donut shape.

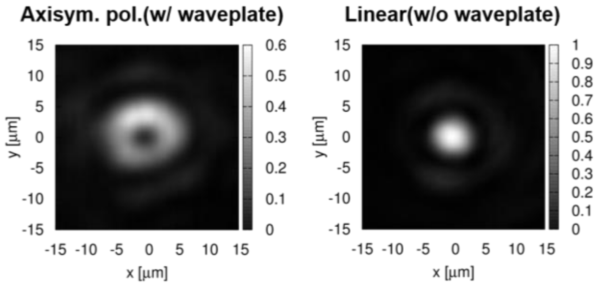

Fig.2. Focal spot profiles of (left)APP and (right)LPP.

In the high-peak power experiments using these laser pulses, while there are no significant differences in the profiles and spectrum of the electron beam between the APP and LPP, the shadowgraph image and the spectrum of side scattering show large differences. In the shadowgraph image, we observed the intense second harmonics generation at the focus point in the case of the APP. Fig.3 shows the spectrum of side scattering in the case of APP and LPP. The spectrum around the fundamental wavelength is broader than the original spectrum of the laser pulse in the case of the LPP. On the other hand, the spectral broadening of side scattering does not occur with using the axisymmetric polarization but still the strong side scattering is observed.

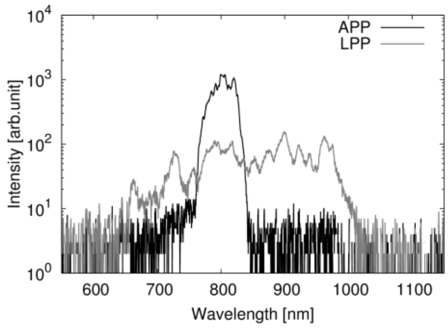

Fig.3. Spectrum of side scattering

The intense second harmonics generation indicates the strong interaction of the intense laser pulse with the dense plasma. The spectral broadening could be caused by the difference of local phase velocities in the plasma wake during the propagation. The spectrum of LPP are modified in the first cavity of the wake and the pulse is scattered at the dense part behind the cavity. No spectral broadening indicates that the scattering of the APP could occur at the high dense area in the early stages. It means the laser pulse directly focuses the electrons by its transverse ponderomotive force and the pulse is scattered at the collective electrons.

4. Summary

We have performed the experiments of LWFA with using the APP. The experimental results as the intense second harmonics generation and the non-spectral broadening of side scattering indicate the transverse ponderomotive force of the APP with donut focal spot creates dense electrons. This feature could be useful for the massive injection of the electrons into the wakefield in the staging acceleration to increase the beam charge.

Acknowledgments

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