DENSITY STRUCTURE EFFECT ON THE ELECTRON ENERGY IN LASER WAKEFIELD ACCELERATOR

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Abstract

The effect of the plasma density structures on the accelerated electron beam energy from the laser wakefield accelerator was studied. The experimental results show that the high energy electron was generated when the plasma density was uniform. The typical plasma density has density downward lamp structure which was measured using a birprism interferometer simultaneously for each shot. In that case the accelerated electron energy was 50 MeV, but in the uniform case, the electron energy was 100 MeV. This might be explained by the acceleration field strength and the acceleration region position dependence on the plasma density. The 1D particle simulation code shows that the density downward ramp structure limits the electron energy.

INTRODUCTION

The development of the ultra high intensity laser makes it possible to accelerate the electron to high energy in short distance using laser wakefield acceleration (LWFA)[1,2]. When the high intensity laser propagates inside the plasma, the electron in the high laser intensity region is expelled to the low intensity region due to the Ponderomotive force. The electron than oscillates due to the restoring force of the ion left behind. This oscillation generates plasma wave which phase velocity is the group velocity of the laser. If the plasma wavelength and the laser pulse duration is comparable, a strong wakefield can be generated. Using this wakefield, the electron can be accelerated to high energy in very short distance, which is called laser wakefield acceleration[2,3]. The plasma wavelength is the function of the plasma density, the plasma density is crucial parameter for the LWFA. In this work, the effect of the plasma density structure on the electron energy was investigated. The experimental results and the 1D particle simulation show that to accelerate electron to high energy the uniform plasma density is crucial.

EXPERIMENT AND SIMULATION

A 20 TW laser system which generates high energy short pulse based on the chrip pulse amplification[4], was used for the experiments. The pulse duration of the laser was 40 fs which was measured using single shot autocorrelator before the experiment. For the experiment, the laser energy was 500 mJ. The laser beam was focused using off axis parabolic mirror with f/#=10. The measured full width half maximum focal spot size was 30 ㎛.

A supersonic gas nozzle was used to generate gas medium. The size of the nozzle was 4 mm long and 1.2 mm wide. The gas density was controlled by the back pressure of the gas nozzle and the laser beam height from the nozzle. Figure 1 shows the experimental setup.

A biprism interferometer was used the measure the plasma density simultaneously. A small part of the laser beam was used for the interferometer. The frequency was converted to second harmonic frequency using BBO crystal. The delay between the laser pulse and the probe light was controlled by the optical delay line of the probe light. In the experiment the delay was set as the main pulse is at the edge of the nozzle.

The electron beam energy was measured using permanent magnet and the Lanex film. The electron path bends due to the magnetic field of the magnet. The angle after the magnet is determined by the energy of the electron. After the magnet, a Lanex film was used to make a mark of the electron position. The beam image on the Lanex film was recorded using ICCD camera.

The integrated charge transformer(ICT) was used to measure the electron bunch charge.

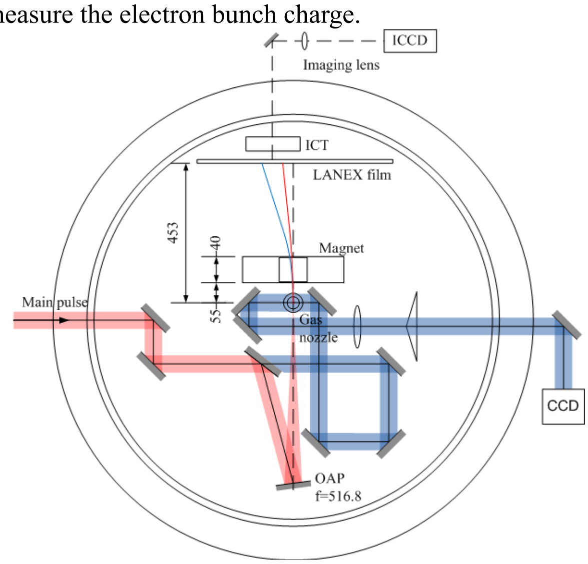

Figure 1: Experimental setup. Red and blue bar shows the direction of the main laser pulse and the probe beam for the interferometer. The laser pulse was focused using off axis parabolic mirror with 516 mm focal length. Just after the nozzle, a permanent magnet was used to bending the electron beam path with respect to the beam energy. The distance from the gas nozzle to the Lanex screen is 450 mm.

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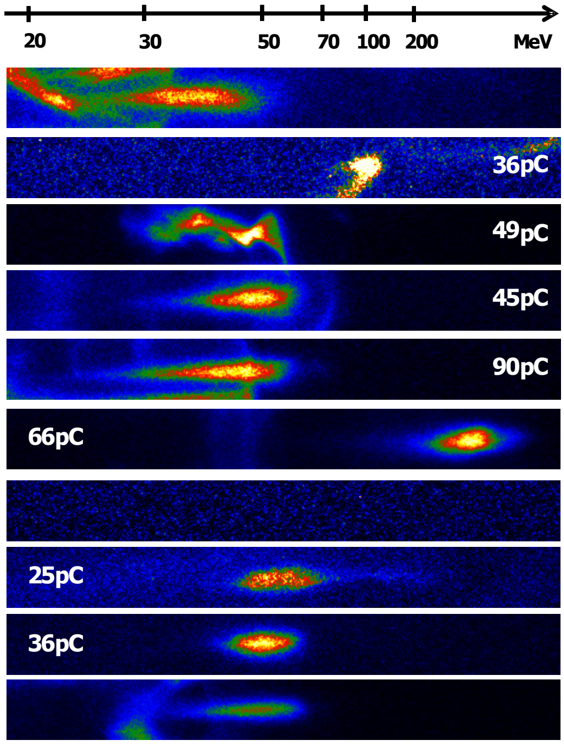

Figure 2: Electron beam energy and charge for 10 consecutive shots. The energy of the beam position is shown in the top bar. The bunch charge is shown in each beam image in white character.

The results of 10 consecutive shots are shown in Fig. 2. The experimental conditions were the same for series of shots. The typical electron energy was 50 MeV with two different high energy. The difference between the high and low energy electron beam case was the plasma density structures. Due to the gas density fluctuation, the plasma was not uniform along the laser propagation direction. The plasma density structure was also changed for different shots. For high energy case the density structure was much different for the low energy cases. There were density downward lamps. The depth of the lamp was different for two different electron energy cases. For high energy electron case, the plasma was more uniform as shown in Fig. 3.

This can be explained by the strength of the acceleration field and the position of the acceleration region. If the density decreases the acceleration field also decreases and the position of the acceleration region lags because the plasma wavelength increases. Density drops before dephasing, the electron goes into the deceleration phase and the acceleration field strength decreases, the electron cannot be accelerated up to high energy. Because of this acceleration field strength and the acceleration region position, the high energy electron was generated only in two more uniform plasma density cases.

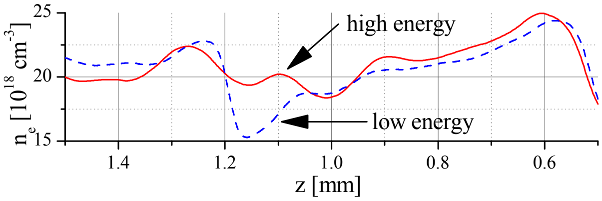

Figure 3: Plasma density structure for low(dashed line) and high energy(solid line) case. The zero position is at the edge of the nozzle. The laser pulse propagates along the z direction(from right to left in the graph).

To simulate the plasma condition dependence on the electron energy, a one dimensional particle in cell code(XOOPIC) was used to simulate the density structure effect on the electron energy[5].

The plasma density structure for the simulation is simply goes down. The electron energy was monitored before the dephasing length.

Figure 4 shows the electron energy and the acceleration field strength for different plasma density condition. The initial plasma density was 2.2×10^{19} cm^{-3}. Figure 4(a) is for the case of uniform plasma density, (b) the slope of the density change was 6.7×10^{15} cm^{-3}/μm, and (c) was 2.3×10^{16} cm^{-3}/μm. The dependence of the acceleration field strength on the plasma density is clearly shown in the simulation results. The simulation results also shows that the acceleration region lags when the plasma density decreases because the plasma wavelength increases. But the accelerated electron positions are almost the same before the dephasing length. The electron easily goes into the deceleration phase for the density downward case. In Fig. 4, the origin of the z axis is at the plasma boundary. Due to the acceleration position lag, the accelerated electrons in density downward transition case are in the deceleration region. This could explain the electron energy limit due to the electron downward density structures.

CONCLUSION

The electron energy dependence on the plasma density structure was investigated by the experiments and simulation. The experimental results shows that the downward density structure limits the energy of the electron. The electron energy decreases when the density goes down more. The particle simulation indicates the this can be explained by the acceleration field strength and the acceleration region position. The acceleration field strength decreases when the plasma density decreases. The acceleration region position lags when the plasma density decreases because the plasma wavelength increases. Due to these two effects, the accelerated electron energy was limited when there is density downward lamp structure. This results will be used to accelerate high energy electron using more uniform plasma density case and the exerpiments are underway.

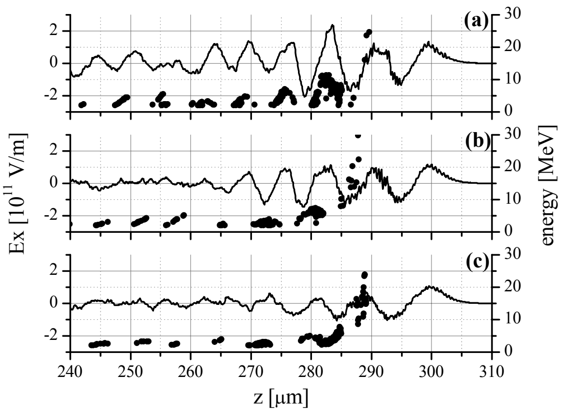

Figure 4: One dimensional PIC results with different density structure. (a) shows the acceleration field strength(solid line) and particle energy(dot) for the uniform density case with plasma density 2.2×10^{19} cm^{-3}. (b) for the density change slope was 6.7×10^{15} cm^{-3}/μm, and (c) for 2.3×10^{16} cm^{-3}/μm.

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