MANIPULATION OF ELECTRON BEAM GENERATION WITH MODIFIED MAGNETIC CIRCUIT ON LASER-WAKEFIELD ACCELERATION

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Abstract

Electron beam injection triggered by intense ultrashort laser pulses, which is called as plasma cathode, is presented. We have studied generation of relativistic electrons by interaction between a high intensity ultra-short laser pulse and gas jet. When a static magnetic field of 0.2 T is applied, the modification of the preplasma cavity, and significant enhancement of emittance and an increase of the total charge of electron beams produced by a 12 TW, 40 fs laser pulse tightly focused in a He gas jet, were observed. And very high stability and reproducibility of the characteristics and position of well-collimated electron beams was detected. We performed an experiment with a magnetic circuit that has more intense magnetic field of 1 T.

INTRODUCTION

The theory of laser plasma acceleration was proposed by Tajima and Dawson in 1979 [1]. The basic concept is to convert the optical electric field energy of a laser pulse to an electron plasma wave having a phase velocity close to the speed of light, and to accelerate charged particles, such as electrons, in an electric field generated in the plasma wave. This laser plasma acceleration has the advantage that the acceleration electric field is much higher (more than three orders of magnitude) than that generated by conventional RF (Radio Frequency) acceleration. In the last few years many notable results in laser plasma acceleration of electrons have been shown [2,3]. We plan a two-step acceleration experiment which accelerates the electron beam generated by the laser plasma cathode with capillary discharge more. The schematic illustration of the plasma cathode experiments with two steps acceleration mechanism is shown in Fig. 1. In the two-step acceleration, a stability of the parameters of the electron beam generated by the plasma cathode is very important.

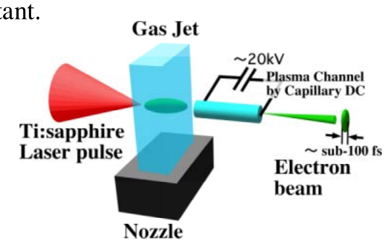

Figure 1: The schematic illustration of the plasma cathode experiments with two steps acceleration mechanism.

EXTERNAL MAGNETIC FIELD EXPERIMENT

Until now, we succeeded in significant enhancement of emittance and an increase of the total charge of femtosecond electron beams produced by a 12 TW, 40 fs laser pulse, after applying a static magnetic field, B～0.2 T, directed along the axis of laser pulse propagation.

The experimental setup is shown in Fig. 2 (see also Ref. [4]). In addition to Ref. [4], the two ring-shaped permanent magnets are set on the laser axis in front of and to the read of the nozzle, making a uniform magnetic field in the gas jet target region in the laser axis direction with B=0.2 T. The solenoid valve is shielded to work under the strong magnetic field [5]. A laser pulse with 12 TW power is focused to the gas jet through a hole of the ring magnets by an off-axis parabolic mirror with a focal length of 178mm $f/3.5$as shown in the inset of Fig. 2. The focus position is ～170 μm from the front edge of the slit nozzle boundary at a height of 1.5 mm from nozzle exit. The focal spot size is 6.0 μm in full width at $1/e^2$ of maximum with < 25 μm Rayleigh length. The maximum laser intensity on the target is estimated to be $I=4.2\times10^{19}W/cm^2$.

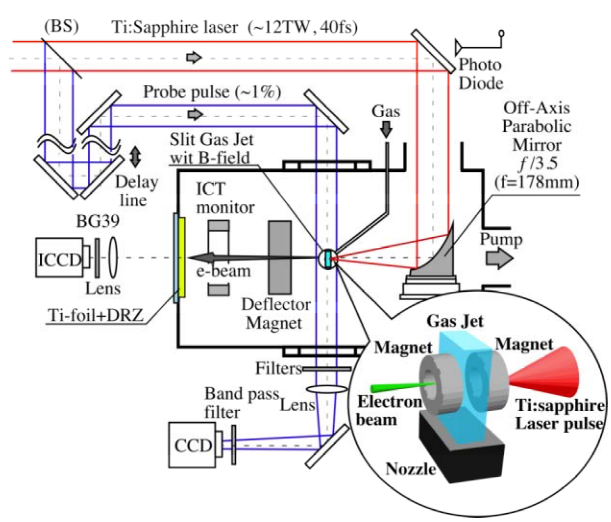

Figure 2: Experimental setup. A supersonic slit nozzle with ring magnets is magnified in the inset.

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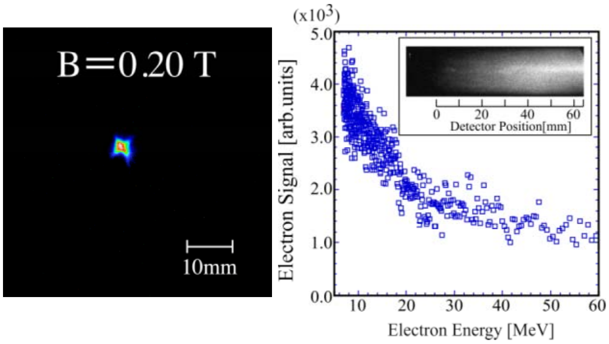

Figure 3: (a) Typical image of electron deposition on the DRZ screen, and (b) typical energy spectra of accelerated electrons. The image on the screen is shown in the inset. N_{He}=4×10^{19}cm^{-3}, B=0.2T and the laser power is 12 TW.

In order to study effects of the external static magnetic field, the measurements of plasma density dynamics by the shadowgraph, the spatial and energy distribution of the electrons, and the charge are taken by single shot. A setup and the details of single shot measurements are described in Ref. [4].

A phosphor screen (DRZ) laminated with a 300 μm titanium foil is put 300 mm from the gas jet to eliminate any effect of the target static magnetic field. The scintillating images on the DRZ by the deposited electrons are recorded by the image-intensified charge coupled device (ICCD). This setup allows one to detect the energy spectrum of the electron beam. The total charge of the electron beam is measured by an integrated current transformer (ICT). The ICT signal is calibrated using the electron beam from the *S*-band linac [11].

The results of the measurements show the strong effect of the magnetic field on the characteristics of accelerated electrons including their emittance. Figure 3(a) shows the spatial distribution of the accelerated electrons obtained with B=0.2 T for a gas density of 4×10^{19}cm^{-3}. A very narrow electron beam at the center of the screen is clearly detected. The size of beam spot is only 3.6mm(FWHM), which corresponds to a divergence angle of ～0.7° . The corresponding transverse geometrical emittance of the electrons in the presence of magnetic field is as small as ～0.02π mm mrad. Figure 3(b) shows the typical energy spectra ofelectrons measured with B=0.2 T. The energy distribution is detected to be Maxwellian with an effective temperature T_h～25 MeV.

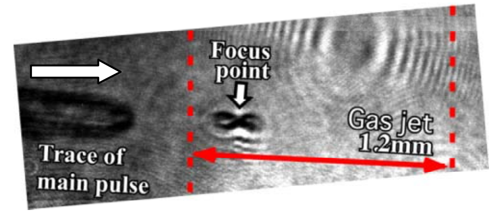

Figure 4: Typical shadowgraph image of the plasma at 1.2ps before the main pulse for N_{He}=4.2×10^{19} cm^{-3}, B=0.2 T and a laser power of 12 TW.

Figure 4 shows typical shadowgraph image of the plasma at ～1.2 ps before the main pulse come to the gas jet with B=0.2 T. The traces of the main pulse, propagation direction of the laser pulse, preplasma, and the gas jet area are marked in Fig. 4 by arrows and dashed lines. The preplasma cavity is modified at the focus point. The preplasma has a two-cone structure with a density peak at the focus point. This can be explained by the fact that the plasma becomes magnetized only near the focus point; therefore a shock wave can propagate only in transverse direction, and there is no longitudinal shock wave. Because of a conelike plasma density distribution at the front of the laser pulse, the diffraction is suppressed and therefore a much higher intensity is achieved at this steep density profile with very efficient self-injection.

We performed a hydrodynamics calculation to examine the growth process of the pre-plasma in a more strong magnetic field. As a result, We confirmed that an optical waveguide structure was made inside the gas jet in the growth process.

From the experiment results which we performed until now, it is confirmed that when pre-plasma which have channel-like structure is formed, quasi-monoenergetic electron beam is generated [4]. So, we made a magnetic circuit which has a more strong magnetic field (B=1.0 T), and performed the experiment with this magnetic circuit (see Fig. 5). The magnetic field distribution of the magnetic circuit was calculated by using RADIA [7].
Fig. 6 shows the plasma observation result when an experiment was performed made by using this magnetic circuit.

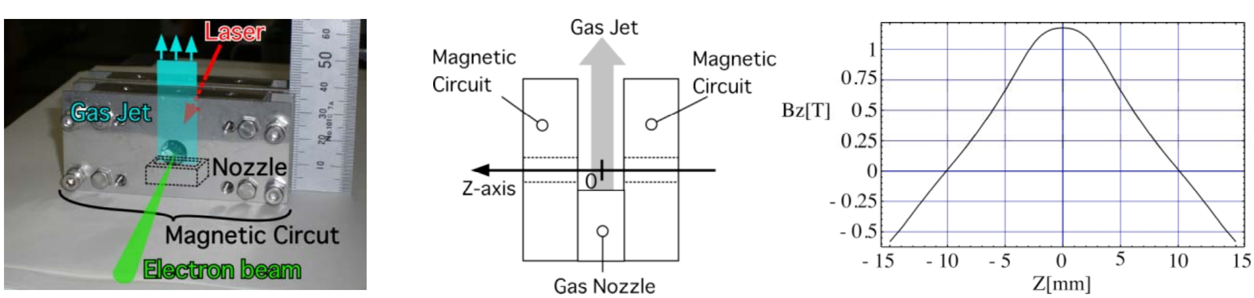

Figure 5: Calculated magnetic flux density of the magnetic circuits on the laser axis and picture of magnetic circuits which generate 1.0 T magnetic field.

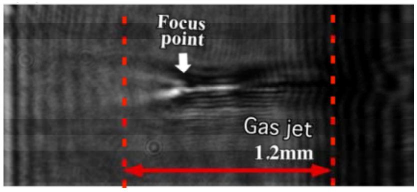

Figure 6: Typical shadowgraph image of the plasma at 1.2ps before the main pulse for N_{He}=4.2 $\times 10^{19}$ cm^{-3} ,B=1.0T and a laser power of 12 TW.

As a result of the experiment, it is confirmed that pre-plasma becomes a long and channel form with applying the strong magnetic field. However, the energy distribution was a Maxwell-like as well as the case of B=0.2 T.

CONCLUSION

We performed the laser plasma cathode experiment with the magnetic circuit which has the strong magnetic field 1.0 T. From the plasma observation, we confirmed the generation of the pre-plasma which is a long channel form. Although in the present experiments the energy distribution is a Maxwell-like, we believe that further manipulation with the pre-plasma including channel formation will lead to a much lower energy spread.

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