ELECTRON BEAM GENERATION FROM SELF-MODULATED LASER WAKEFIELD ACCELERATOR

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Abstract

From 2001, the laser wakefield accelerator has been studied at the Center for Advanced Accelerator (CAA) of Korea Electrotechnology Research Institute (KERI). For this study, 2 TW, 700 fs Ti: sapphire and Nd: Glass hybrid type laser was installed and self-modulated laser wakefiled acceleration (SM-LWFA) has been tried as the first step. Recently, electron beam generation from SM-LWFA is successfully performed and its energy and charge are measured as 6 MeV and 2 nC, respectively. In this paper, we describe experimental details and present characterization results of the generated electron beam.

INTRODUCTION

After Tajima and Dawson introduced the new idea of charged particles acceleration with the plasma wakefield[1], laser and plasma based accelerator has been focused as a candidate of the next generation particle accelerator. When the laser pulse passes through the plasma, electrons are pushed out to the outside direction so that the wake wave is generated behind the laser pulse. Inside the wake wave, one can find the longitudinal electric field and it can be used for charged particle acceleration. This electric field is three orders of magnitude stronger than the conventional radio frequency (RF) based accelerators so that the size of the accelerator can be reduced dramatically. In addition to the wake generation, if the laser pulse width λ_l is longer than plasma wavelength λ_p then the laser pulse divided into several parts when it passes through the plasma. These multi pulses laser strengthen the wakefield resonantly so that the energy of the accelerated particle can be increased. This acceleration scheme is called as the self-modulated laser wakefield accelerator (SM-LWFA).

From 2001, Center for Advanced Accelerator (CAA) at Korea Electrotechnology Research Institute (KERI) starts its ambitious project to make a table-top high-energy accelerator. For this project, 2 TW laser was installed in KERI and the SM-LWFA experiment has been performed as the first step. In this paper, we present recent results of this SM-LWFA experiment. Details of the experimental setup are described and results of the electron beam characterization are presented.

EXPERIMENTAL SETUP

For the SM-LWFA experiment, a new laser system (Positive Light) is installed successfully. This laser system is a hybrid type of Ti:sapphire/Nd:glass and produces a laser pulse of 1.4 J energy and 700 fs pulse at the wavelength of 1.054 μm. The beam size is 30 mm diameter and its intensity profile is a homogeneous one. This laser pulse is focused by an off-axis parabolic mirror on the front edge of the gas jet to produce the plasma and the wakefield. The focal length of the parabolic mirror is 5 cm and the size of the focused beam is 10 μm. To obtain high pressure gas, a commercial gas jet (General Valves) is used. The diameter of the gas jet is 800 μm and maximum gas pressure is 70 bar. The duration time of the gas jet is 2 ms.

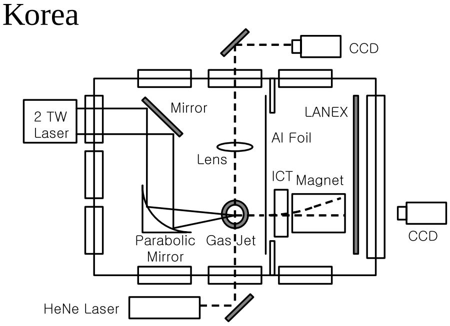

Figure 1: Experimental setup for SM-LWFA. The top view CCD is not shown in this figure.

From the previous experiment of the gas jet characterization, it is known that the gas density has a Gaussian distribution to the radial direction and an exponential decay to the gas flow direction[2]. This means that the position of the gas jet should be controlled with great accuracy because the density of the plasma is a critical parameter of the SM-LWFA experiment. In the SM-LWFA, the modulated laser wavelength is decided by the plasma wavelength λ_p, so that the plasma density is related with the number of electron beams. Moreover, the plasma density is closely related to the strength of the wakefield, so that the total charge and the maximum energy of the electron beam are depend on the plasma density. Thus, we mount the gas jet on a motorized XYZ translator to focus the laser beam on the optimum position. However, although one can control the absolute position of the gas jet in μm order by using the XYZ translator, the relative distance between the focal point and gas jet is still unknown. In addition, the laser spot can not be seen by the naked eye directly. To solve this problem, we decided to use the plasma fluorescence and installed two CCD cameras outside the experimental chamber. One CCD camera is placed on the top of the experimental chamber and the other is putted on the side. Two magnifying lenses are used in both directions for bet-

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ter resolution, as well. Moreover, on the side view, a HeNe laser is installed for a back-lighting so that one can observe the plasma and gas jet simultaneously. By using these two CCD cameras, we can monitor the plasma position and calculate the relative distance between the laser spot and gas jet in the transverse and longitudinal direction.

After it is generated from the laser and plasma interaction, the electron beam comes to the beam diagnostic system. We used an integrating current transformer (ICT) to measure the total charge of the electron beam. The ICT (BERGOZ instruments) is coupled with and beam charge monitor (BCM) and the BCM send its output voltage to a digitizing oscilloscope. This output voltage is proportional to the total beam charge so that one can calculate the total charge directly. Between the gas jet and ICT, an aluminum foil (16μm) is inserted to block the laser beam and remove electrons of which energy is lower than 40 keV. After the ICT, an electric dipole magnet and a LANEX film (Kodak) are installed for the energy measurement of the electron beam. Electrons are bent out when they pass through the magnetic field and their trajectories are decide by their energies. After pass through the magnetic field, these electrons hit the LANEX film and their scintillating image is taken by a CCD camera behind the LANEX film. Finally, one can estimate the energy of the electron beam by measuring the beam position under various magnetic fields.

EXPERIMENTAL RESULT

By measuring the total charge of each focal position, we determined the optimum position of the focal spot. Three dimensional search is made and their results are shown in Fig. 2. To the longitudinal direction (y) the total charge is increased sharply and reached its maximum value at the front edge of the gas jet orifice. After the front edge, it is decreased gradually (see Fig. 2 a). On the other hand, to the transverse direction (z), the total charge of the electron beam is decreased as the distance between the gas jet surface and the focal spot position is increased (see Fig. 2 b). However, it is not an exponential decay as the neutral gas density case. Measured maximum charge of the electron beam is 2.2 nC where the laser pulse power is 1.4 TW and the He gas pressure is 70 bar.

After finding the optimum focal spot position, we investigated the laser pulse energy and He gas pressure dependence of the beam charge. The laser pulse energy is changed from 0.3 to 1 J and He gas pressure was increased from 20 to 70 bar. Figure 3 shows that the total beam charge is linearly proportional to the laser pulse energy and He gas pressure. This because the higher laser pulse makes larger amplitude of the wake wave and the wave breaking field is the function of the plasma density.

Figure 4 is the image size of the electron beam at the different LANEX distance. Here, the LANEX distance is the distance between the gas jet and the LANEX film. From this result, one can find that the beam size is increased rapidly after it is generated. This comes from the space

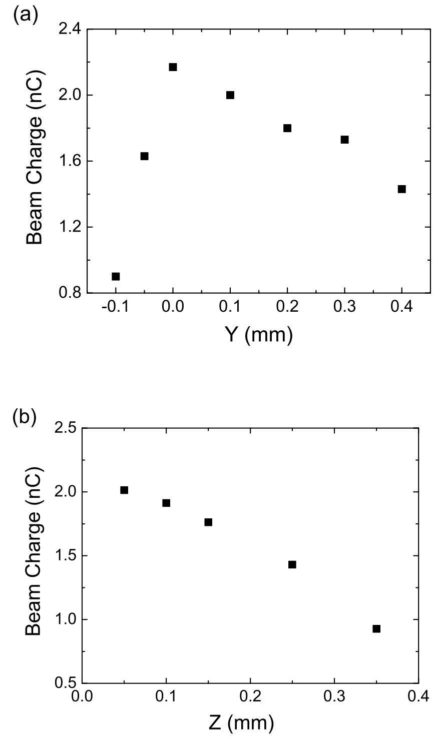

Figure 2: Measured beam charge at different gas jet position. (a) Total charge vs. longitudinal position of gas jet. 0 means that the laser focal spot is placed on the front edge of the gas jet orifice. (b) Total charge vs. distance between gas jet surface and focal spot point . The laser power is 1.4 TW and He gas pressure is 70 bar in both case.

charge effect. The electron beam has a high charge and short pulse width so that electrons inside the beam experience strong repulsive force. However, note that the size of the electron beam increases linearly after 7 cm. This means that the space charge effect is negligible after few centimeters because the beam size is already big enough.

In addition, there is another interesting physics in the SM-LWFA electron beam. In the literature, it is reported that the energy of the electron beam core is higher than that of the outer part[3]. This comes from the energy spread and the space charge effect. The electron beam from the SM-LWFA has 100% energy spread and the number of the high energy electron is smaller than that of the low energy electron. Under this condition, electrons are redistributed according to their energies while they propagate in vacuum. Let's assume that there are two electrons which have different energies at the similar position then they are pushed out to the outward direction by other electrons. Even though the space charge force is same on two electrons, they have different trajectories because of their energies. After all, as time goes on, low energy electrons are distributed on the outer part of the electron beam and high energy ones are remain in the core. Experiment result of this phenomenon

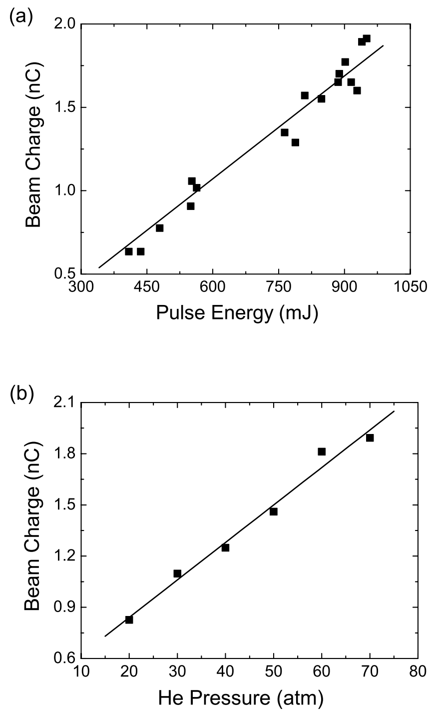

Figure 3: Total beam charge as a function of laser power and He gas pressure. The distance between the gas jet surface and the focal spot point is 0.1 mm. He gas pressure is 70 bar in (a) and the laser power is 1.4 TW in (b).

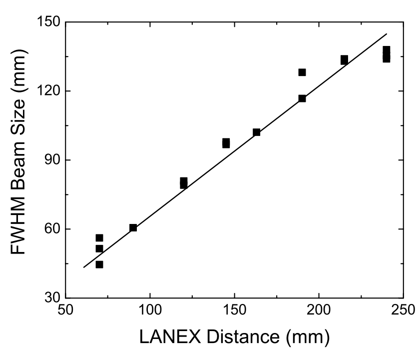

Figure 4: Measured beam size at different LANEX distance. Here, the LANEX distance means the distance between the gas jet and the LANEX film.

is presented in Fig. 5. To measure the energy of the core electrons, we installed an energy diagnostic system along the longitudinal axis. The energy diagnostic system is consisted of a 5 mm diameter collimator, dipole magnet and LANEX film. The distance between the gas jet and collimator is 10 cm and the length of the dipole magnet is 10 cm. After the energy measurement of core electrons, we installed the energy diagnostic system on the 5 degrees line from the longitudinal axis for the outer part elec-

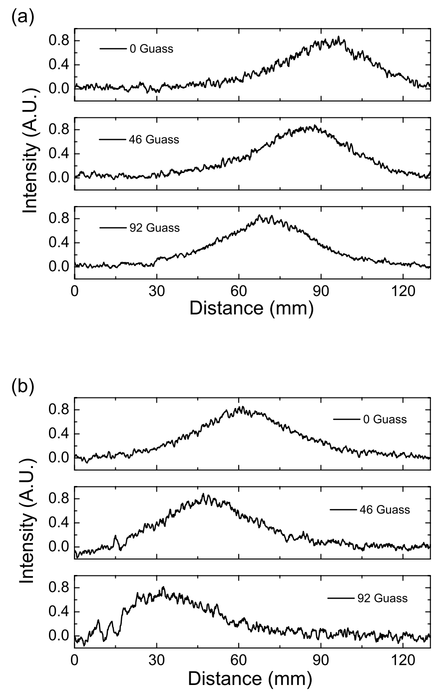

Figure 5: Electron beam profiles under different magnetic fields when the collimator, dipole magnet and LANEX film are installed on the longitudinal axis (a), and 5 degree off axis (b). The laser power is 1.4 TW and He gas pressure is 70 bar in both case. Calculated energies are 6 MeV and 700 keV, respectively.

trons. As shown in Figures, the transverse beam profiles are measured under several magnetic fields. Calculated energies along the longitudinal axis and 5 degrees off axis are 6 MeV and 700 keV, respectively.

SUMMARY

From 2001, laser wakefield accelerations have been studied at KERI to make a table-top high-energy accelerator. As the first step, an electron beam generation is conformed from the SM-LWFA experiment. The maximum charge of the electron beam is 2.2 nC and the maximum energy is 6 MeV. The total charge was proportional to the laser energy and He gas pressure. It is also noticed that the space charge effect generates the rapid increase of the beam size and the redistribution of electrons to the radial direction according to their energies.

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