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Generation of relativistic high-energy electrons by laser wakefield acceleration at KERI

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I. Introduction

There are various issues in laser and plasma-based advanced accelerator research. One of important tasks of plasma accelerators is how to generate high-energy electron beams with a small energy spread. For this purpose, we are going to conduct a series of experiments on the laser wakefield acceleration at KERI, where a T^3 laser system is used for laser plasma interactions. The first experiment of the plan is the self-modulated laser wakefield acceleration (SM-LWFA), in which the rather long (>> plasma wavelength λ_p) laser pulse is self-modulated into shorter pulses due to the Raman scattering instability and plasma electrons are self-injected into the acceleration phase. This is a simplest acceleration method in laser and plasma-based acceleration mechanisms. Hence, we start with this experiment due to its simplicity. However, it should be noted that SM-LWFA leads to a large energy spread (~ 100 %) as background plasma electrons are randomly injected. Thus, another experiment will be performed after the SM-LWFA experiment to achieve a smaller energy spread. In this paper we report the ongoing research activities and results, and the future plan is introduced a well.

II. Table-top terawatt laser system

The laser system for the advanced accelerator research at KERI is a hybrid type of Nd:glass and Ti:sapphire. The oscillator (Time-Bandwidth GLX-200) is a glass laser that can produce 200 fs laser pulses at 76 MHz by using the so-called SESAM (Semiconductor Saturable Absorber Mirror) technology for stable fs mode-locking. The laser pulses are sent to the Ti:sapphire regenerative amplifier, where the laser pulse is stretched to 1.4 ns and then it is amplified by the Ti:sapphire rod pumped by the frequency-doubled Nd:YLF laser (Spectra-Physics Evolution-X). In this way the regenerative amplifier can produce laser pulses with an energy of 0.4 mJ/pulse at 500 Hz. The output from the regenerative amplifier is sent to three stages of Nd:glass amplifier system and the laser pulse is amplified to 2

J/pulse. And then this pulse is compressed by two gratings with an efficiency of 70 % and the pulse duration is reduced to 700 fs. Hence, 1.4 J/pulse is eventually sent to the laser-plasma interaction chamber.

III. SM-LWFA experiment

As mentioned in Sec. I, we started with the SM-LWFA experiment as it is a simplest mechanism in laser and plasma-based advanced accelerators. A schematic of the experimental setup for this experiment is shown in Fig. 1. The 2 TW (1.4 J/700 fs) laser beam is sent to the laser-plasma interaction chamber in which the laser beam is focused to a supersonic gas jet with a focused spot size of about 10 microns by the gold-coated parabolic mirror. The gas jet has a diameter of 1 mm and its neutral gas density profile was measured by the Mach-Zehnder interferometer. The measurement result shows that the density profile is almost Gaussian across the transverse direction and the neutral gas density is in the range of 10^{18} to 10^{19} cm^{-3}. Intensity of the focused laser beam is on the order of 10^{18} W/cm^{2}, so the electric field is strong enough to ionize He atoms to a plasma. When the intense laser beam with a duration of 700 fs interacts with the He plasma, some background plasma electrons are self-injected into the acceleration phase of a self-modulated laser wakefield. The accelerated electrons have an energy spread of 100 %, so the low energy and high energy electrons are redistributed when they propagate along the longitudinal direction. The low energy electro have a very strong space-charge force and they diverge very rapidly. Our main interest is in the high energy electrons, so a collimator with a 2 mm diameter is setup to cut off the low

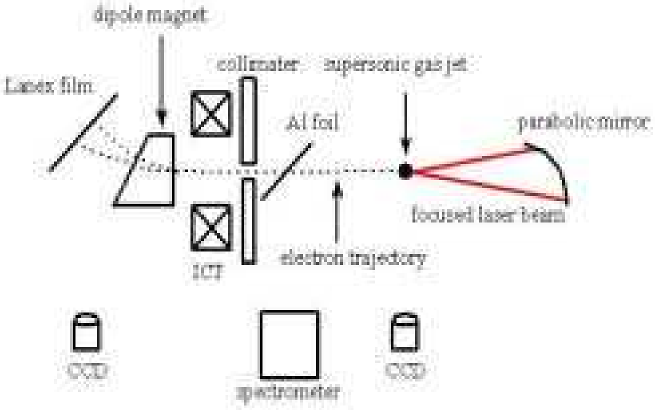

Figure 1: Schematic of the experimental setup for the self-modulated laser wakefield acceleration.

energy electrons. The electrons, which passed the collimator, propagate through the integrating current transformer for charge measurement. After that, the electrons are sent to the dipole magnet and beam imaging plate (phosphor-based Kodak Lanex film) to measure energy and energy spread. In order to know the focused laser beam location and to view the longitudinal plasma images, two CCD cameras are installed at 90°. The transmitted laser light is reflected by the 45 ° thin Al foil and is sent to the spectrometer to measure the plasma density based on the Raman scattering method.

The beam charge may be dependent on the plasma density. To investigate this issue the laser energy was fixed at 0.9 J and then the He gas backing pressure was varied from 20 bars to 70 bars. This measurement indicates that the beam charge increases almost linearly to the backing pressure that is linear to the gas density at the laser plasma interaction point (see Fig. 2). Figures 2 show that charge per pulse is a few nC. The beam duration would be around the laser pulse duration that is 700 fs. Based on these parameters the peak current is estimated to be on the order of kA. But the beam diameter at the exit of the gas jet will be less than the plasma wavelength λ_p (~ 10 μm) and the energy of the electrons will be in the range of MeV. Hence, the electron beam is severely space charge dominated. For this reason the beam diverges very rapidly as it propagates.

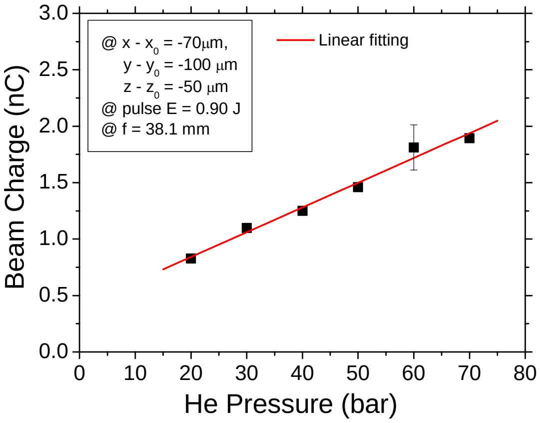

Figure 2: Electron beam charge as a function of the He backing pressure. This result implies that the beam charge is linearly proportional to the plasma density.

IV. Quasi-monoenergetic electron beam generation

Generation of qusi-monoenergetic electron beams is a hot issue in the advanced accelerator community as it is very important. Unfortunately nobody in the world knows a controllable way to generate quasimonoenergetic electron beams. We tried a very thin coolimator method to have such a small energy spread. In other words, a very small collimator with a diameter of 1mm was used to select only onaxis high energy electrons. In this way most low energy electrons, which have stronger space-charge force and diverge more strongly, can be cut off by the collimator, so that quasi-monoenergetic electron beams can be obtained. Our experiment shows that this method works and the result is shown in Fig.3. It shows that the peak of the profile is in the high energy regime of the spectrum. Hence, the small collimator method would be one of ways to generate quasimonoenergetic electron beams.

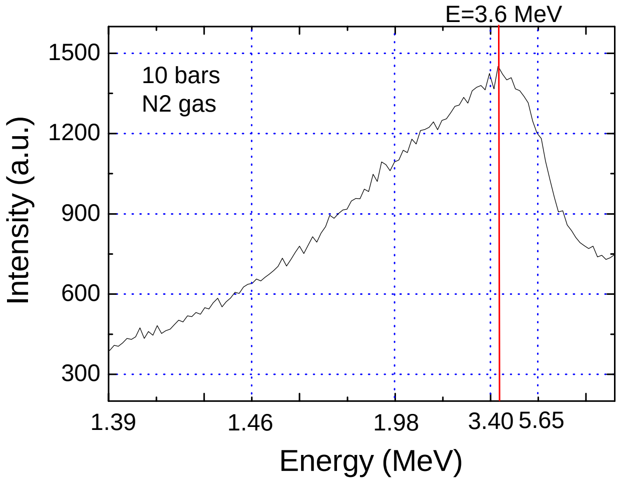

Figure 3: Electron beam energy profile when a collimator with a diameter of 1 mm was used.

V. Summary

Some of ongoing research activities at KERI were briefly introduced. One of them is the self-modulated laser wakefield acceleration. The result shows that we generated MeV-level high-energy electrons with a few nC per bunch and the electron beam is highly space-charge dominated, so the beam expands explosively as it propagates. This beam has an energy spread of 100 % naturally. In order to produce beams with a small energy spread, we tried the small collimator method and our experiment shows that this method works. Hence, the small collimator method would be one of ways to generate quasimonoenergetic electron beams.