PROGRESS OF THE LASER-PLASMA ACCELERATION RESEARCH AT KERI

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Abstract

An intense laser pulse can produce a plasma wake wave, which has an extremely strong electric field. This electric field can be used for electron acceleration with a ultrastrong high acceleration gradient (100 times or more compared with RF-based conventional accelerators). We have an experimental program on the laser-plasma acceleration research at KERI (Korea Electrotechnolgy Research Institute), where a 2 TW (700 fs in pulse duration) Nd:glass/Ti:sapphire lasser system and a 20 TW (30 fs in pulse duration) Ti:sapphire laser system (located at GIST-APRI) are used. In this paper, we present an overview of the experimental results for the laser-plasma acceleration research.

INTRODUCTION

RF-basedd conventional accelerators have a limited accelerating electric field of ~ 100 MV/m. Compared with this field, a focused laser beam has a much stronger electric field. For example, if the intensity is I=1018 W/cm2, which can be nowadays easily achieved with a table-top terawatt laser system, the field strength is E=3 TV/m. However, the laser electric field can not be directly used for particle acceleration because the electric field is transverse. This problem can be solved if the laser beam is sent into a plasma, so the laser field is converted into a strong longitudinal plasma wake field that is almost in the same order of magnitude as the laser field itself [1]. There are several ways to excite a strong laser-plasma wake wave. One way is to send a rather long (longer than the plasma wavelength) laser pulse, so the plasma wave can be resonantly excited by a pulse train from the Raman scattering instability. This is called the self-modulated laser wakefield acceleration (SM-LWFA). Another way is to send a short laser pulse (pulse duration ~ plasma wavelength) and this can excite the plasma wake wave almost resonantly as well. We have an experimental program on the SM-LWFA and resonant LWFA at KERI in collaboration with GIST-APRI (Gwangju Institute of Science and Technology-Advanced Photonics research Institute). In this paper, we show some experimental results from the SM-LWFA and LFWA research.

EXPERIMENTAL RESULT ON THE SELF-MODULATED LASER WAKEFIELD ACCELERATION

For the self-modulated laser wakefield acceleration experiment, we used the 2 TW (1.4J/700 fs) Nd:glass/Ti:sapphire hybrid type laser system at KERI. The experimental schematic is shown in Fig. 1. The 2 TW laser beam with a diameter of 5 cm is focused to a small spot (~ 10 μm in diameter) by the gold-coated parabolic mirror in the He supersonic gas jet (backing pressure ~ tens of bars, gas jet diameter=0.8 mm), so the He gas is ionized to a plasma by the strong electric field of the laser beam. Due to the interaction of the plasma and the laser beam, a self-modulated laser wakefield is generated and some background plasma electrons are randomly injected into the acceleration phase. The injected electrons are accelerated and the produced beam passes through the dipole magnet. And then it arrives at the LANEX film (a kind of phosphor film). This measurement gives an energy and energy spread of the generated electron beam. The beam charge is measured with an ICT (integrating current transformer) that is located after the thin LANEX film (made by KODAK). In this experiment, the generated electron beam has a continuous energy spectrum because plasma electrons are randomly injected into the acceleration phase. Hence, we used a very small pinhole-like collimator with a diameter of 1 mm to select only high energy electrons that are distributed mainly along the axis.

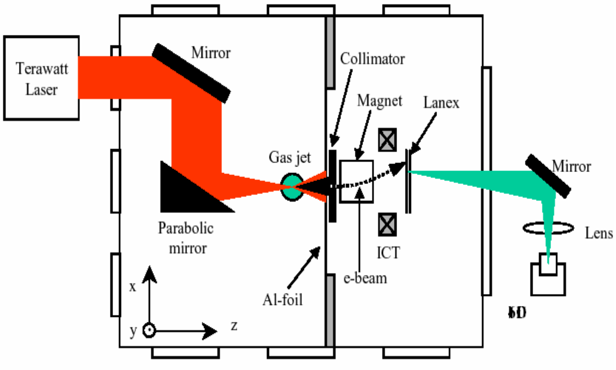

Figure 1: Schematic for the SM-LWFA experiment.

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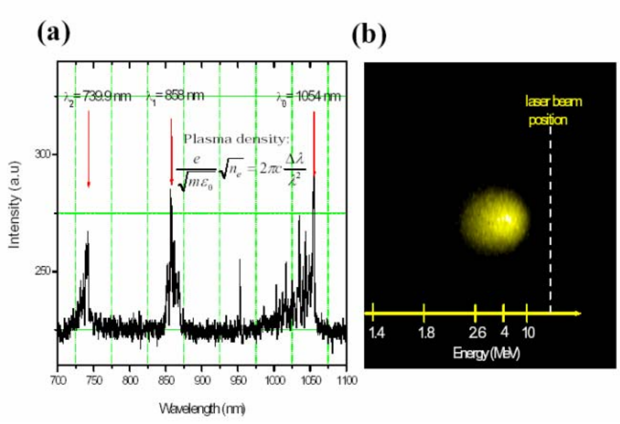

Figure 2: (a) Spectrum of the Raman forward-scattered light and (b) energy spectrum of the generated electron beam.

Interaction of the long laser pulse and the plasma produces the Raman forward scattered light and Fig. 2(a) shows its spectrum. It shows that the spectrum has a few side bands and analysis of the result gives the plasma density ($n_p = 10^{19} \sim 10^{20}$ cm-3). Our comparison of this result and interferometric measurement of the neutral gas density gave the same result, which implies that the He gas is almost 100 % ionized with the focused 2 TW laser beam. Figure 2(b) shows the energy spectrum of the generated electron beam from the SM-LWFA experiment, in which a 1-mm diameter collimator was used to select only high energy electrons along the axis. The measured result shows that the beam is quasimonoenergetic, reaching up to ~10 MeV in energy. Although this method is not a perfect way to generate a monoenergetic beam, it is a quite useful and practical way for quasimonoenergetic beam generation from the SM-LWFA.

EXPERIMENTAL RESULT ON THE RESONANT LASER WAKEFIELD ACCELERATION

In addition to the SM-LWFA experiment, a separate experiment for the resonant laser wakefield acceleration was performed with the 20 TW (30 fs) Ti:sapphire laser system of GIST-APRI. In this case, the plasma density is tuned for the plasma wavelength $\lambda_p \cong c\tau$, where c is the light speed and τ is the laser pulse duration. The used gas was also He and the gas jet has dimensions of 4 mm by 1.2 mm (the laser propagates along the 1.2 mm direction). We measured the generated electron beam with the same diagnostic tools as Sect. 2. By tuning the plasma and laser parameters carefully, we could sometimes generate quasimonoenergetic electron beams. One example is shown in Fig. 3, in which the energy spectrum of the electron beam (measured after a dipole magnet) is clearly quasimonoenergetic. It shows that the peak energy is around 35 MeV and the maximum energy is about 70 MeV. However, it should be pointed out that generation of this kind of quasimonoenergetic electron beam is quite unstable, so it can not be repeated with high probability. This is probably due to highly nonlinear injection of the plasma electrons into the acceleration phase of the wake wave. Therefore, a good way for controllable injection is required for realization of the laser-plasma accelerators and this is one of the most important research issues in the laser-plasma accelerator community.

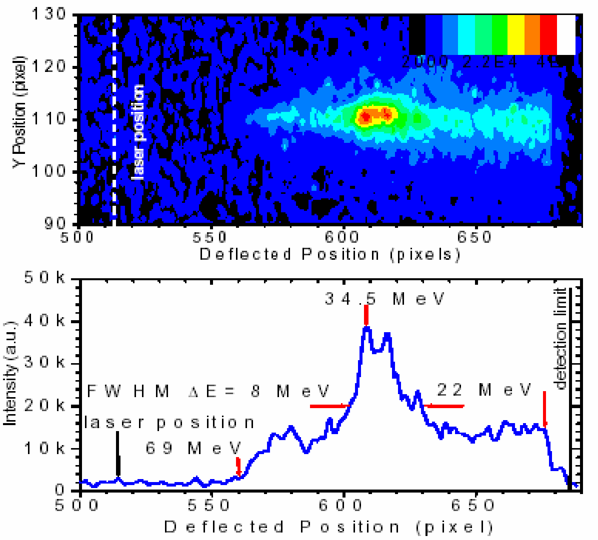

Figure 3: (a) Energy spectrum of the generated electron beam from the resonant LWFA experiment and (b) profile of the energy spectrum.

QUASIMONOENERGETIC ELECTRON-BEAM GENERATION FROM THE DENSITY TRANSITION

Several ideas were proposed to produce such beams using lasers [2,3]. One of them is to use a sharp downward density transition. According this idea, some background plasma electrons can be self-trapped by the laser wakefield when an intense laser beam pulse propagates through a sharp downward density transition. At the transition the wavelength of the wake wave increases suddenly so that some background plasma electrons are self-injected into the local acceleration phase of the wakefield and a small energy-spread beam can be generated. This was confirmed by particle-in-cell simulations before, and now we are doing an experiment to verify the idea. Although the experiment is still in the preliminary stage, we found a promising result already.

For this experiment, one needs a sharp downward density transition in the plasma and we produced it with an expanding plasma channel. In other words, the high power Ti:sapphire laser beam at GIST was split into two parts and then one of them was used to produce a plasma channel and the other was sent at right angle to cross the plasma channel. The laser pulse for the plasma channel was not compressed, so its pulse duration is rather long

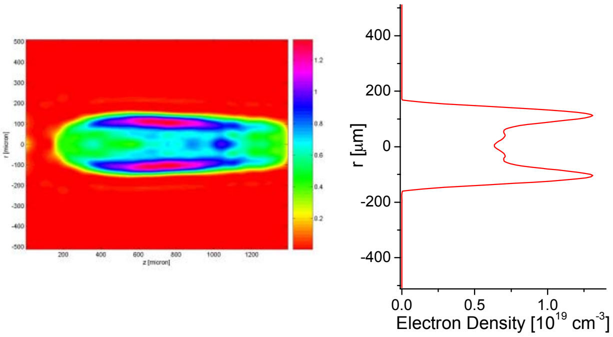

Figure 4: Generated plasma channel (left) and its density profile. In the left figure, the long (~300 ps) laser pulse propagates in the horizontal direction and the channel expands rapidly.

(~300 ps, 500 mJ). When it propagates in the He gas jet, it produces a plasma channel and it expands radially. In this process, the density profile becomes steep outward due to a nonlinear effect and the compressed high power laser beam is focused near the downward part of the second density peak, so a laser plasma wake wave passes through a sharp downward density transition. Here, it should be noted that the plasma channel of Fig. 4 is surrounded by a neutral He gas and this neutral gas is converted to a 100-%-ionized plasma as the high power laser beam propagates through the gas. So the overall plasma density profile has two density peaks with a flat plasma background and the trapped plasma electrons can be accelerated in the plasma with a flat density profile. Figure 5 shows one example of the results, where a quasimonoenergetic electron beam was generated. In this experiment, the time delay between the two laser pulses was fixed to 4 ns due to a technical problem and we could not optimize the situation. Nevertheless, the generated electron beam showed a quasimonoenergetic property. Of course, it should be remembered that this is a preliminary result and there are still quite many issues to clarify. Hence, we will continue this research to answer all questions and to optimize the result.

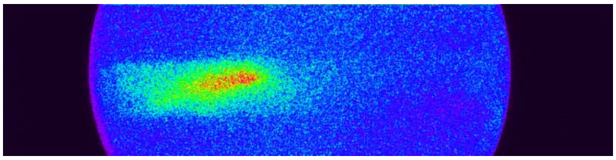

Figure 5: Energy spectrum of the generated electron beam from the density transition experiment.

CONCLUSIONS

Laser-plasma accelerator research has made an amazing progress around the world for the past several years. One of the most important achievements is production of quasimonoenergetic electron beams. We have also made a good progress in this direction at KERI. Although the methods for quasimonoenergetic beam generation are not perfect yet, we are going ahead for better achievement and we believe that the final goal will be achieved in the future.

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REFERENCES

[1] T. Tajima and J. M. Dawson, Phys. Rev. Lett. 43, 267 (1979)
[2] D. Umstadter, J. Kim, E. Dodd, Phys. Rev. Lett. 76, 2073 (1996).
[3] E. Esarey, R. F. Hubbard, W. P. Leemans, A. Ting, and P. Sprangle, Phys. Rev. Lett. 79, 2682 (1997).
[4] H. Suk et al., J. Opt. Soc. Am. B 21, 1391 (2004); H. Suk et al. Phys. Rev. Lett. 86, 1011 (2001).