18PB-002

Development of the high quality electron source using the staged Laser Wakefield Acceleration

ステージングレーザー航跡場加速を用いた高品質電子源の開発

K. Iwasa[1)], T. Hosokai[2)3)], S. Masuda[2)3)], N. Nakanii[2)3)], Z. Jin[2)], Y. Mizuta[1)], A. Zhidkov[2)3)], N. C. pathak[2)], N. Takeguchi[1)], K. Sueda[2)], M. Kando[4)], R. Kodama[1)2)5)]
岩佐 健太[1)], 細貝 知直[2)3)], 益田 伸一[2)3)], 中新 信彦[2)3)], 金 展[2)], 水田 好雄[1)], ジドコフ アレクセイ[2)3)], パサック ナヴィーン[2)], 竹口 直輝[1)], 末田 敬一[2)], 神門 正城[4)], 兒玉 了祐[1)2)5)]

[1]Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan
[2]Photon Pioneers Center, Osaka University, 2-8 Yamada-oka, Suita, Osaka 565-0871
[3]Japan Science and Technology Agency (JST), CREST, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871
[4]Kansai Photon Science Institute, Japan Atomic Energy Agency, 8-1-7 Umemidai, Kidugawa, Kyoto 619-0215
[5]Insititute of Laser Engineering, Osaka University, 2-6 yamada-oka, Suita, Osaka 565-0871
[1]大阪大学工学研究科　〒565-0871　大阪府吹田市山田丘2-1
[2]大阪大学光科学センター　〒565-0871　大阪府吹田市山田丘2-8
[3]科学技術振興機構CREST　〒565-0871　大阪府吹田市山田丘2-1
[4]日本原子力研究開発機構関西　〒619-0215　京都府木津川市梅美台8-1-7
[5]大阪大学レーザーエネルギー学研究センター　〒565-0871　大阪府吹田市山田丘2-6

Stable and monoenergetic electron beams are necessary for ultrafast electron imaging with using laser wakefield acceleration. Quasi-monoenergetic electron beams, which have electron energy of ~MeV, are generated by using staged laser wakefield acceleration driven by two coaxial laser pulses. Furthermore, electron energy spectra changed by controlling the injection timing of two pulses.

1. Introduction

Laser Wakefield Acceleration (LWFA), the particle acceleration method by the plasma wave driven by intense laser pulses, has a high accelerating gradient (~100 GeV/m), and it can generate electron beams with large charges (~nC), ultra-short pulse duration (~fs), and low emittance. Thanks to these characteristics, LWFA has been expected as a high quality electron source for single shot electron imaging of ultrafast phenomena on materials science. In application of LWFA to the ultrafast electron imaging, stable and repeatable electron beams which have narrow energy spread are necessary. However, electron beams form LWFA has a thermal energy bunch, and less stability.

Recently, we have obtained the low divergence electron beam which has the pointing stability by control of the preformed plasma by applying the outside magnetic field. In order to generate quasi-monoenergetic electron beams, we had the experiments of the two staged LWFA. In this paper, we present results of the above experiments.

2. Stable electron injection from LWFA

The instability of electron beams has been considered as a problem because LWFA use plasma as an acceleration medium. However, stable electron injection is enabled by control a propagation of the high intensity laser pulse with the plasma optics positively. High intensity ultra-short laser pulses (~10 fs) produced by CPA (Chirped Pulse Amplification) method have pre-pulse (ns~ps) ahead a main pulse. The collecting intensity of the main pulse decreases by diffracting it because of a refractive index gradient made by pre-plasma which is produced by a pre-pulse, and its collecting profile is worsened. Due to this the electric charge of electron beams decreases, and a collecting profile, repeatability also turns worse. The condition of the pre-plasma is controlled by applying the outside magnetic field (B ~ 0.2 T) to the gas target, the collecting of the main pulse is stabilized, and the generation of the stable electron beams is succeeded[1]. These electron beams have the pointing stability as good as 0.3 mrad(rms) and controllability of the electron beam

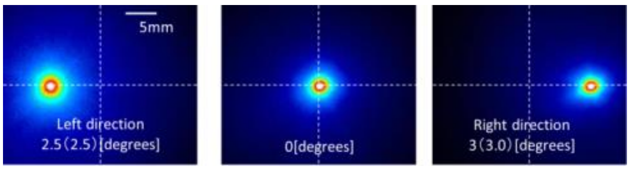

Fig.1: Direction control of electron beam by external magnetic field (B=0.2 T).

direction by control of the outside magnetic field as shown in Fig.1[2]. Furthermore, generation of the quasi-monoenergetic electron beam has been observed by activating the laser wakefield in the deep plasma channels with their length of ~1 mm because of the pre-plasma having an optical waveguide function like an optical fiber[3][4]. These techniques support the staged laser acceleration as the stable electron injector at the first stage of the multi staged acceleration.

3. Staged Laser Wakefield Acceleration

Generally, electron beams occurring by plasma wave breaking have thermal energy spectra, and it is a problem in applying to the electron imaging. Recently, the staged LWFA is studied in order to improve these energy spectra into quasi-monoenergetic one with keeping their high stability. The staged LWFA is consisted of two coaxial wakefields, one is the nonlinear wake-field for injecting electron bunches, and the other is the linear wakefield for narrowing electron energy spectra by phase rotation.

The experiment of the staged LWFA was performed at P3 800 nm Ti: sapphire chirped pulse amplification (CPA) laser system at Osaka University. An outline of the experimental set up is given in Fig.2. The laser system generate with the pulse energy up to 660 mJ, 30 fs pulse width. The laser pulse was divided into two pulses and focused to the gas target with f/3.5 off-axis parabolic mirror (OAP) and f/20 OAP. The pulse with short focus length produced the first wakefield to generate electron bunches, the other with long focus length produced the second wakefield for additional acceleration. Helium gas is used as the target, its density ~10^{19} cm^{-3}.

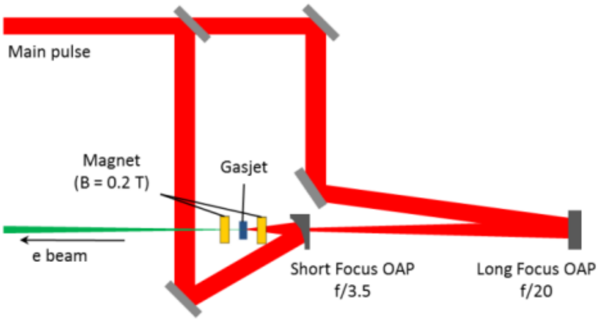

Fig.2: Setup of the staged LWFA.

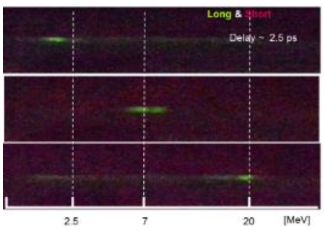

Fig.3 : Image of Energy Spectrometer

The formation of the channel by the long focus pulse was observed behind the focus point of the short focus pulse, and the long scattering light behind the strong scattering light was observed. It means electron is injected at the point of strong scattering light by the short focus pulse, and the long wakefield for additional acceleration is produced by the long focus pulse. As given in Fig.3, generation of quasi-monoenergetic (~MeV) electron beams by the staged LWFA was confirmed. Moreover, electron energy spectra changed by changing the injection timing of two pulses. These results clarified the fact that electron generated at the first wakefield are additionally accelerated by the second wakefield, and quasi-monoenergetic electron energy can be controlled by the injection timing of two pulses.

4. Summary

We have studied the staged LWFA for the ultrafast single shot electron imaging. Stability and repeatability are important for the multi staged acceleration. Although electron beams had problems in their pointing stability and repeatability, we could obtain the repeatable low divergence electron beams which have the pointing stability of 0.3 mrad (rms) and controllability of their direction by control of the outside magnetic field. Quasi-monoenergetic electron beams, which have electron energy of ~MeV, are generated by using staged laser wakefield driven by two coaxial laser pulses. Furthermore, electron energy spectra changed by controlling the injection timing of two pulses. That supports ultrafast electron imaging systems as a high quality electron source.

References

[1] T. Hosokai, et al., Phys. Rev. Lett., vol. 97, 075004 1-4(2006).
[2] N. Nakanii, et al., Phys. Rev. E, to be submitted.
[3] T. Hosokai, et al., Appl. Phys. Lett., Vol. 96, 121501(2010).
[4] Y. Mizuta et al., Phys. Rev. STAB., 15, 121301(2012).