19aC1-4

Ponderomotive Electron Acceleration in Vacuum Using Radially Polarized Laser Pulse
軸対称偏光レーザーパルスによるポンデロモーティブ電子加速

Shinichi Masuda[1,2], Alexei Zhidkov[1,2], Tomonao Hosokai[1,2], Nobuhiko Nakanii[1,2], Naveen Pathak[1,2], Yoshio Mizuta[3], Kenta Iwasa[3], Naoki Takeguchi[3], Masaki Kando[4], Michiaki Mori[4], Hideyuki Kotaki[4], and Ryosuke Kodama[1,3]
益田伸一[1,2], ジドコフ アレクセイ[1,2)], 細貝知直[1,2)], 中新信彦[1,2)], パサック ナビーン[1,2)], 水田好雄[3)], 岩佐健太[3)], 竹口直樹[3)], 神門正城[4)], 森道昭[4)], 小瀧秀行[4)]、兒玉了祐[1,3)]

[1)] *Photon Pioneers Center, Osaka University, 2-1 Yamadaoka Suita, Osaka 565-9871, Japan*
[2)] *CREST, Japan Science and Technology Agency, 7 Gobancho, Chiyoda, 102-0076 Japan*
[3)] *Graduate School of Engineering, Osaka University, 2-1 Yamadaoka Suita, Osaka 565-9871, Japan*
[4)] *Kansai Photon Science Institute, Japan Atomic Energy Agency, 8-1-7 Umemidai, Kizugawa, Kyoto 619-0215, Japan*
大阪大学 光科学センター 〒565-9871 吹田市山田丘2-1
CREST 科学技術振興機構 〒102-0076 千代田区五番町7
大阪大学 工学研究科 〒565-9871 吹田市山田丘2-1
日本原子力研究開発機構 関西光科学研究所 〒619-0215 木津川市梅美台8-1-7

An electron bunch generated by laser ponderomotive acceleration in vacuum has extremely short bunch length, small energy spread and small longitudinal emittance. Especially, bunch length is in a range of sub-femtosecond. It is expected to be an extremely short electron source. Electron scattering can be suppressed by longitudinal fields of tightly focused laser pulse and acceleration efficient can be improved by using radially polarized laser pulse. Assignment of initial electrons for the ponderomotive acceleration scheme is a difficult problem. We propose new experiments using dense electrons produced by laser wake field acceleration scheme as an initial electrons target.

1. Introduction

Direct electron acceleration by electromagnetic waves such as a laser beam field had been proposed and studied theoretically [1-4] since the concept of optical maser (laser) was developed. In the so called relativistic ponderomotive acceleration scheme, electrons in the laser field are quivering in the transverse direction by the electric field and in the longitudinal direction by the magnetic field and then are pushed in longitudinal direction [5]. Because an ultra short laser pulse has a large intensity gradient and a large longitudinal ponderomotive potential, it can accelerate electrons in longitudinal direction. However most electrons are scattered by transverse ponderomotive force of the focused laser beam [6]. Radially polarized laser pulse has a donut-shape transverse intensity profile so that electrons near the laser axis can be trapped by the transverse ponderomotive potential and transverse electron scattering is effectively suppressed [7,8]. In addition, the longitudinal component of the electric field near the laser focus effectively accelerate electrons in the longitudinal direction [3,8] and also suppress transverse electron scattering [9]. Numerical simulations show that the ponderomotive acceleration scheme can produce high quality electron bunches characterized by an extremely short electron bunch, small energy spread, small transverse and longitudinal emittances [7-9].

The laser ponderomotive acceleration scheme in vacuum is expected for not only ultra short electron bunch generation but also electron bunch compression, high speed electron beam sweeping, and so on.

The electron ponderomotive scattering and acceleration was observed experimentally [10-12]. In these experiments, relativistic electron acceleration was principally demonstrated and observed electron scattering angle was agreed with the theoretical prediction [11,12]. However, the number of electrons accelerated was not enough for applications, because it is difficult that a large amount of initial electrons are placed within the focused region. We propose new experiments of the ponderomotive acceleration scheme.

2. Numerical Simulation

In order to estimate electron acceleration with our 25fs, 40TW Ti:Sapphire laser system, numerical simulations were conducted. Electron motion in the radially polarized laser pulse was calculated by sixth order Runge-Kutta method.

Initial electrons with the kinetic energy from 0MeV to 5MeV are distributed around the laser axis. Initial position of the eletrons was determined with respect to the initial energy so that the electrons overlap laser pulse around the focal point. Laser power was supposed at 20-40TW. Focal spot size was 6μm. Figure 1 shows the energy dependence of angler distribution of electrons. Electrons are accelerated with narrow can be obtained.

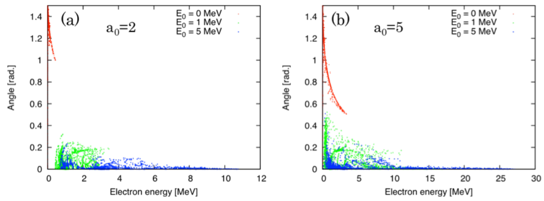

Fig. 1. Simulation results of laser normalized vector potential of the laser pulse at (a) a_0=2 and (b) a_0=5. Initial electron kinetic energy is 0 MeV (red dots), 1 MeV (green dots), and 5 MeV (blue dots), respectively.

3. Ponderomotive Acceleration Experiment

3.1 *Experimental setup*

The target is an electron beam produced by the laser wakefield acceleration (LWFA) that can control the electron spectrum. The first laser pulse produces dense low energy electrons extracted from a gas jet target. The initial electrons have short bunch length and the second laser pulse accelerate the electrons by the relativistic ponderomotive acceleration scheme as shown in Fig. 2. The second laser pulse is radially polarized which is converted from linearly polarized Gaussian mode by eight segments l/2λ wave plate as shown in Fig. 3.

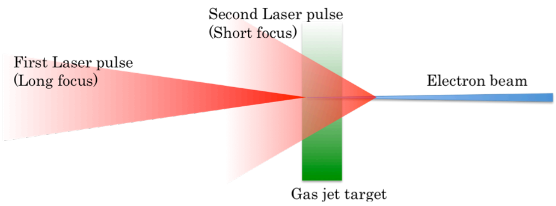

Fig. 2. Experimental setup

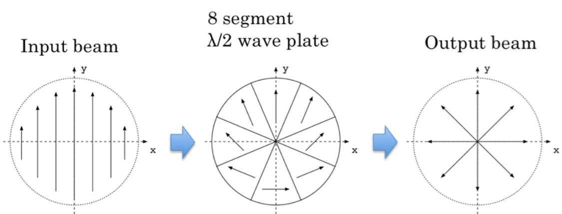

Fig. 3. Production of radially polarized laser pulse.

3.2 *Preliminary experiment*

We have constructed laser system, laser transport and focusing system, and electron transport line for the LWFA experiments. Figure 4 (a) shows the focusing system for two laser pulses. It was observed that the linearly polarized Gaussian laser pulse was converted to the radially polarized laser pulse as shown in Fig. 4 (b) and (c). Transmission efficiency of the wave plate was 90%.

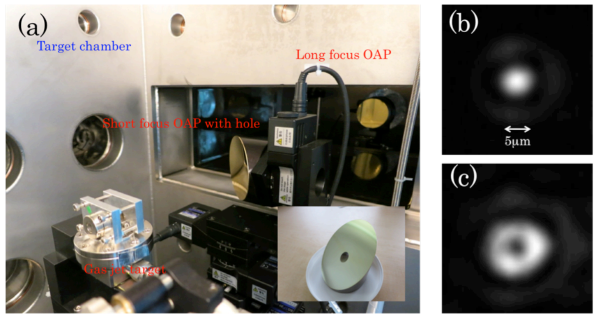

Fig. 4. (a) Focusing system. (b) Laser spot pattern of linearly polarized pulse. (c) Radially polarized laser pulse

3. Summary

We have been preparing the experiment of relativistic laser ponderomotive acceleration scheme with the radially polarized laser pulse. Conversion of the polarization of ultrashort high intense laser pulse was confirmed by preliminary experiment.

References

[1] K. Shimoda: Appl. Opt. **1** (1962) 33.
[2] M. O. Scully and M. S. Zubairy: Phys. Rev. A **44** (1991) 2656.
[3] S. Takeuchi, R. Sugihara, and K. Shimoda: J. Phys. Soc. Jpn. **63** (1994) 1186.
[4] E. Esarey, P. Sprangle and J. Krall: Phys. Rev. E **56** (1995) 5443.
[5] E. S. Sarachik and G. T. Schappert: Phys. Rev. D **1** (1970) 2738.
[6] F. V. Hartemann, S. N. Fochs,G. P. Le Sage, N. C. Luhmann, J. G. Woodworth, M. D. Perry, Y. J. Chen, and A. K. Kermann: Phys. Rev. E **51** (1995) 4833.
[7] G. V. Stupakov and M. S. Zolotorev: Phys. Rev. Lett. **86** (2001) 5274.
[8] Q. Kong, S. Miyazaki, S. Kawata, K,. Miyauchi, K. Nakajima, S. Masuda, N. Miyanaga, and Y. K. Ho: Phys. Plasmas **10** (2003) 4605.
[9] S. Masuda, M. Kando, H. Kotaki, and K. Nakajima: Phys. Plasmas **12** (2005) 013102.
[10]G. Malka, E. Lefebvre, and J. L. Miquel: Phys. Rev. Lett. **78** (1997) 3314.
[11] J. L. Chaloupka and D. D. Meyerhofer: Phys. Rev. Lett. **83** (1999) 4538.
[12] C. I. Moore, A. Ting, S. J. McNaught, J. Qiu, H. R. Burris, and P. Sprangle: Phys. Rev. Lett. **82** (1999) 1688. C.I. Moore, A. Ting, T. Jones, E. Briscoe, B. Hafizi, R. F. Hubbard, and P. Sprangle: Phys. Plasmas **8** (2001) 2481. A. Ting, D. Kaganovich, D. F. Gordon, R. F. Hubbard, and P. Sprangle: Phys. Plasmas **12** (2005) 010701.