Available online at www.sciencedirect.com
ScienceDirect
Physics Letters A 370 (2007) 310–315
PHYSICS LETTERS A
www.elsevier.com/locate/pla

Double pulse laser wakefield accelerator

Changbum Kim [a,*], Jin-Cheol B. Kim [a], Kukhee Kim [b], In Soo Ko [a], Hyyong Suk [c]

[a] *Department of Physics, Pohang University of Science and Technology, Pohang 790-784, Republic of Korea*
[b] *National Fusion Reserch Center, Daejeon 305-333, Republic of Korea*
[c] *Center for Advanced Accelerators, Korea Electrotechnology Research Institute, Changwon 641-120, Republic of Korea*

Received 27 January 2006; received in revised form 9 February 2007; accepted 18 May 2007

Available online 25 May 2007

Communicated by F. Porcelli

Abstract

Two-dimensional simulation studies are performed for modified laser wakefield acceleration. After one laser pulse, another identical laser pulse is sent to the plasma to amplify the wake wave resonantly. The simulation results show that the number of injected electrons is bigger than that of the single pulse case and the beam energy is higher as well. In addition, increase of the transverse amplitude is noticed in the wake wave after the second laser pulse. This shows that the transverse motion of the wake wave enhances the wave breaking for strong injection and acceleration of electron beams.

PACS: 52.38.Kd; 52.38.Bv; 52.35.Mw

Keywords: Laser wakefield accelerator; Resonant laser plasma accelerator; 2-D particle in cell simulation; Electron injection and acceleration

1. Introduction

Laser and plasma based accelerators have been focused in recent years because they can accelerate electrons to a relativistic high-energy within a very short range. When an ultra-intense ($>10^{18}$ W/cm^2) laser pulse passes through high-density plasmas, a wake wave is generated behind the laser pulse. Inside this wake wave, there is a longitudinal electric field which can be used for electron acceleration [1]. This electric field is stronger than that of a conventional radio frequency (RF) accelerator by three orders of magnitude. For example, the maximum electric field of the laser wakefield is on the order of 100 GV/m when the plasma density $n_0 = 10^{18}$ cm^{-3} is used. For the study of laser and plasma based accelerators, several acceleration schemes have been developed. They include the laser wakefield accelerator (LWFA) [1], plasma wakefield accelerator (PWFA) [2], plasma beat-wave accelerator (PBWA) [3–5], self-modulated laser wakefield accelerator (SM-LWFA) [6–8], and wakefield accelerators driven by multiple electron pulses or laser pulses [9,10].

The LWFA, among these acceleration scheme, was introduced for the first time. As a laser pulse propagates through an under-dense plasma ($\lambda_p > \lambda_0$), the electric field of the laser pulses pushes electrons to the radial direction to generate the plasma wake wave. The pulse width of the laser is equal to or less than the plasma oscillation wavelength. Thus, the LWFA is free from plasma instabilities since they generally require many plasma periods to grow. For its advantages, the LWFA has been widely studied in experiments as well as simulations after the development of femto-second high-power lasers. Recently, breakthrough results were achieved by obtaining "quasi-mono energetic" electron beams from LWFA experiments [11–13]. These results showed the "state of the art" of the LWFA research because the large energy spread had been a problem of LWFA experiments. Another interesting thing is that their experimental conditions are different from each other to produce quasi-mono energetic electron beams. One is plasma densities just above a threshold required for wave breaking [11], the other is a plasma density channel to guide a relativistically in-

* Corresponding author.
E-mail address: chbkim@postech.ac.kr (C. Kim).

0375-9601/$ – see front matter
doi:10.1016/j.physleta.2007.05.060

tense laser [12], and the third is a plasma bubble that traps and accelerates plasma electrons [13]. These different conditions show that one can obtain quasi-mono energetic electron beams in various ways and still have chance to generate high-quality electron beams from another methods. In addition, it is reported that all experimental results show energy fluctuations in their electron beams, so that stable methods for electron beam acceleration will be the next issue after generations of mono-energetic electron beams.

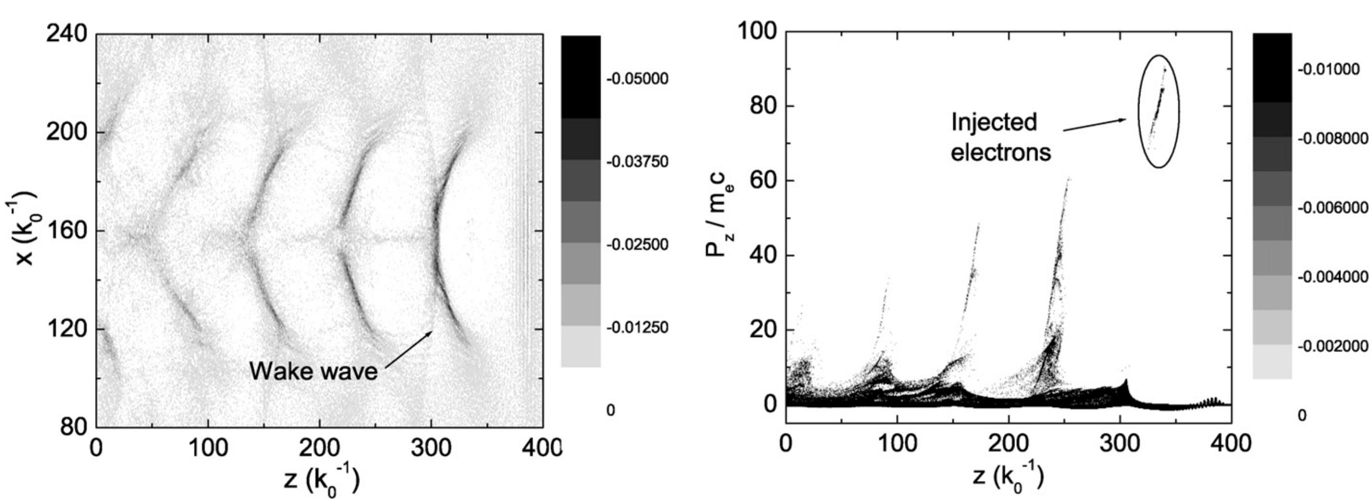
In 1994, a resonant laser plasma accelerator (RLPA) was suggested [14,15]. In this acceleration scheme, a series of short laser pulses amplified the wake wave resonantly. By using a train of resonant pulses, the strength of the wakefield could increase by more than an order of magnitude. This RLPA combines virtues of other acceleration schemes, but has several more advantages. First, the maximum wake wave amplitude is achieved by optimizing independent pulse widths and delays between pulses. Second, the electron phase detuning can be avoided by using the lower plasma density. Third, the use of multiple laser pulses reduces the peak intensity, so that several laser plasma instabilities can be suppressed such as stimulated Raman scattering [16], modulation and filamentation instabilities [8], and so forth. In spite of these advantages, the RLPA has not been verified with experiments because its condition is difficult to satisfy. For the resonance condition, the delay between the driving laser pulses must increase while the laser pulse width decreases for each subsequent driving pulse. These conditions are not achieved in any laboratory yet.

We performed two-dimensional (2-D) Particle-In-Cell (PIC) simulations. In our simulations, we tried a modified LWFA simulation by using two identical laser pulses with a controllable delay. We believe this double pulse LWFA can provide an alternative way of an RLPA experiment, because two pulses with a given delay can be achieved by using a simple interferometer. By inserting an interferometer inside a chirped pulse amplification system, an amplified laser pulse can be divided into two identical pulses with a controllable delay. Here, the interferometer should be installed between the amplifier and compressor to prevent a temporal diffraction and a frequency shift resulting from pulse shaping [17].

In this study, the simulation result of double pulse LWFA is compared with the single pulse case. From this comparison, we show that the energy and charge of the electron beam can be increased by using the double pulse LWFA. Interestingly, the wake wave after the second laser is expanded to the transverse direction. This result implies that the transverse motion of the wake wave plays an important role in the injection and acceleration of electrons. Next, an optimization is tried by changing the delay between two pulses and the laser pulse width. When the laser pulse width is longer than the plasma wavelength, another high-charge injection is noticed with the increase of the wake wave period. Lastly, different power ratios of the two laser pulses are tried to find a better condition for electron beam generation.

2. 2-D PIC simulation on double pulse laser wakefield accelerator

We performed 2-D PIC simulations by using the OSIRIS code [18]. The OSIRIS code uses a moving window for the simulation of laser plasma interactions. This moving window propagates into the plasma with the speed of light in free space. The moving window has 900×500 grid points and there are 12 cells in one laser wavelength to the transverse (x) and longitudinal direction (z). For the simulation window, a periodic boundary and the Lindman open-space boundary are used for the x and z axis, respectively. The plasma density increases from 0 to 1×10^{19} cm^{-3} over a distance of 0.25 mm. The plasma density continues for a 1 mm distance after that. The direction of the laser propagation is from left to right. After the plasma reaches its maximum density, the laser is focused and the spot size at the focal point is 10 μm. The laser wavelength is 800 nm and the laser polarization is s-polarization.



(a) (b)

Fig. 1. Simulation results of single pulse case. (a) Electron distribution plot (x, z) of the plasma and (b) the phase space plot (p_z, z) at $t = 3780\omega_0^{-1}$. A short ($\tau_0 = 0.75\lambda_p$) laser pulse is sent to the plasma and its a_0 is 2.12. The plasma density is 1×10^{19} cm^{-3}.