23P177-B

Two-dimensional Particle-in-Cell Simulation on Forming Plasma Micro Optics in Laser Wake Field Acceleration

レーザー航跡場加速におけるプラズママイクロオプティクス形成に関する2次元PICシミュレーション

Keigo Makito[1], Alexei Zhidkov[2,3], Shinichi Masuda[2,3], Yoshio Mizuta[1], Shohei Kajino[1], Akinori Nishida[1], Nobuhiko Nakanii[2,3], Tomonao Hosokai[2,3] and Ryosuke Kodama[1,2,3]
牧戸啓悟[1]，アレクセイジドコフ[2,3]，益田伸一[2,3]，水田好雄[1]，梶野祥平[1]，
西田明憲[1]，中新信彦[2,3]， 細貝知直[2,3]，兒玉了祐[1,2,3]

[1]*Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita-shi, Osaka 565-0871, Japan*
[2]*Photon Pioneers Center, Osaka University, 2-8 Yamadaoka, Suita-shi, Osaka 565-0871, Japan*
[3]*Japan Science and Technology Agency (JST), CREST*
[1]大阪大学大学院工学研究科　〒565-0871　吹田市山田丘2-1
[2]大阪大学光科学センター　〒565-0871　吹田市山田丘2-8
[3]科学技術振興機構（JST），CREST

Generation of laser wake field using a high contrast laser pulse in argon gas is investigated by two-dimensional particle-in-cell simulation including optical field ionization for control of electron beam characteristics. The quality of the wake field structure is strongly affected by ionization during the pulse propagation. The structure disappears at higher gas density: the gas density threshold for the wake field generation is found to be about 1×10^{18} cm^{-3}.

1. Introduction

Sources of femtosecond mono-energetic electron beams with low divergence and high charge are required in the field of ultra-fast transient imaging. Laser wake field acceleration (LWFA) may enable to develop such electron beam sources. In order to produce electron beam by LWFA, control of the wake field generation and electron injection is essential.

A plasma structure named "plasma micro optics" is to control the wake field. It has been used in experiments with successful generation of high quality electron bunches by focusing a femto-second intense laser to a helium gas target with a controllable magnetic field [1, 2]. In terms of the gas species of the target, argon is reported to produce that kind of structure at much higher densities than helium targets [3]. Although experiment on generating the plasma micro optics using argon target has also performed, its principle is not revealed yet because of its complicated physical process. For clarifying this problem, as a basic research for forming the plasma micro optics, we firstly carry out simulations on generation the wake field in argon gas.

There are several physics involved in the wake field generation: self-focusing, refraction of laser light, and neutral gas ionization. Among all these factors, the ionization may play an important role resulting in the difference of the wake field structure as shown in Fig. 1. In this paper, we present results of two-dimensional particle-in-cell (PIC) simulations including optical field ionization to investigate how this ionization effect to the generation of the wake field during the laser pulse propagation.

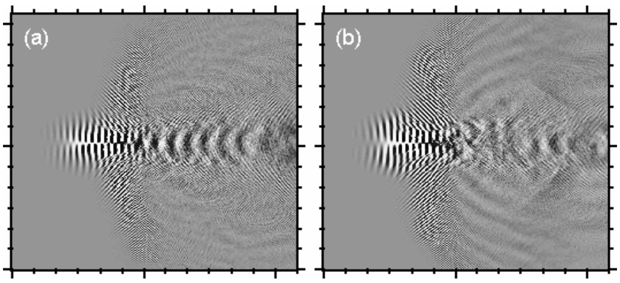

Fig.1. Laser wake field generated in (a) fully ionized plasma, (b) gas with ionization process.

The optical field ionization rate α is given by following:

$$\alpha = 4\omega_A \frac{E_A}{E}\left(\frac{I_i}{I_H}\right)^{5/2} \exp\left[-\frac{2}{3}\frac{E_A}{E}\left(\frac{I_i}{I_H}\right)^{3/2}\right]$$

where ω_A and E_A are the atomic frequency and electric field respectively, I_H and I_i are the ionization potentials of hydrogen and the atom under consideration.

2. PIC Simulation

Table I. Basic conditions of laser pulse

Wavelength	800 nm
Intensity	3×10^{19} Wcm^{-2}
Pulse duration	40 fs
Spot size	16 μm in diameter

We performed 2D PIC simulations of laser wake field generation using high contrast laser pulse in argon gas. The code employed the Buneman scheme for current weighting, variable particle weight for calculating optical field ionization. The code also employs moving window with the absorbing boundary.

2.1 *Conditions of simulation*

The cell size of calculation mesh and time step were set to 0.05 μm and 0.08 fs. And we used 4 particles per cell. Laser pulse whose conditions are shown in Table I propagated from right to left. The pulse focused at 150 μm from its initial position where argon gas density ramp starts increasing linearly along the laser axis (X-axis); the density ramp length is 50 μm, then the plasma is uniform.

2.2 *Gas density dependency*

Spatial distribution of the laser wake field in the gas jets with different density, are shown in Fig. 2 after the pulse propagated over 300 μm. All coordinates are given in $k = c/\omega$ unit. The other parameters were set as in Table I. In case of the low gas density, the wake field has clear structure while the high density case, its structure no longer exists. The gas density threshold of the structure breakdown is found to be about 1×10^{18} cm^{-3}.

2.3 *Dependencies on laser parameters*

We also performed the calculations changing the laser parameters. Fig. 3 shows the wake field distribution at different (a) pulse intensity of 3×10^{20} Wcm^{-2} and (b) its spot size of 32 μm in diameter. The other parameters were fixed as shown in Table I. As this figure shows, the wake field structure disappeared in the higher intensity case. In this case, a steeper density gradient is made in the transverse direction and stronger refraction results in the faster wave-breaking. In contrast, with a wider spot size the gradient becomes smaller with weaker refraction and better structure of the wake.

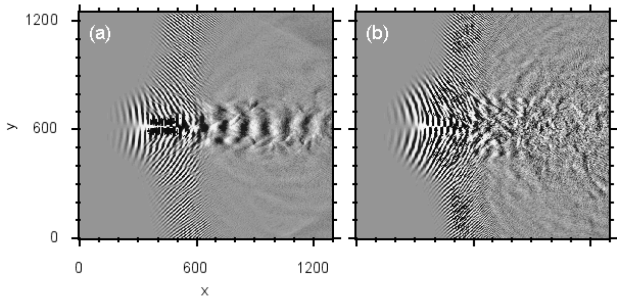

Fig.2. Wake field generation in the gas with density (a) 0.7×10^{18} cm^{-3}, (a) 2×10^{18} cm^{-3}

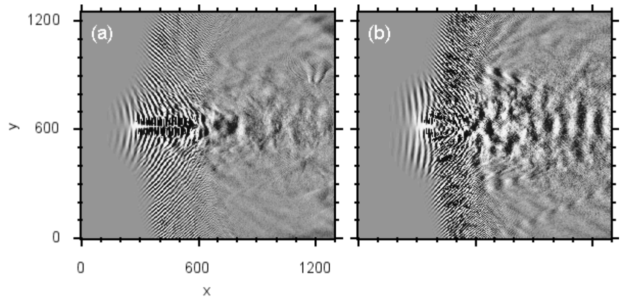

Fig.3. Wake field generation using laser with (a) intensity 3×10^{20} Wcm^{-2}, (b) spot size 32 μm in diameter

3. Conclusion

In summary, we have performed 2D PIC simulations on laser wake field generation after high contrast laser pulses in argon gas to investigate the effects of ionization during the laser pulse propagation, as a basic research for forming the plasma micro optics. The quality of the wake field structure is strongly affected by ionization during the pulse propagation. The structure disappears in case of higher gas density, and higher laser intensity. The gas density threshold for the wake field generation is about 1×10^{18} cm^{-3}.

Acknowledgments

This work was supported by CREST (Core Research for Evolutional Science and Technology) of the Japan Science and Technology Agency (JST).

References

[1] T. Hosokai et al.: Phys. Rev. Lett. **97** (2006) 075004.
[2] T. Hosokai et al.: Appl. Phys. Lett. **96** (2010) 121501.
[3] M. Mori et al.: Phys. Rev. STAB. **12** (2009) 082801.