*34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, O-3.003 (2007)*

ELECTRON SURFACE ACCELERATION BY USING CAPILLARY TARGETS

T.Nakamura[1], K.Mima[1], H.Sakagami[2], T.Johzaki[1], and H.Nagatomo[1]

[1]*Institute of Laser Engineering, Osaka University, Osaka, Japan*

[2]*Department of Simulation Sciences, National Institute for Fusion Sciences, Toki, Japan*

1. Introduction

Recently interactions of relativistic intensity laser pulses with targets having sharp density edge have been realized due to the improvements of technique to reduce the pre-pulse level. The interactions of the main pulse with targets make significant differences between with and without preplasmas from the perspective of dominant electron acceleration processes, energy coupling to plasmas and so on. When the scale length of preplasma is smaller than the wave length of the laser pulse, the ponderomotive acceleration plays a dominant role. This results in the generation of an electron jet propagating towards the laser direction. In this case, the laser irradiation angle becomes the critical parameter which determines the electron energy transport direction [1]. When the incident angle becomes larger than about 70 degree, surface magnetic and electric fields are generated which confine high energy electrons along the surface.

2. Electron surface acceleration

When the surface electric and magnetic fields are formed, an electron acceleration takes place along the surface [2]. To explain the surface acceleration process, 2D PIC simulations are performed. The target density is 50 n_c where n_c denotes the critical density, and the scale length of preplasma is 0.1 μm. The laser pulse whose intensity of 1.0×10^{19}W/cm^2 with a uniformity in transverse direction irradiates the target from the left boundary with 75 degree incidence. The surface field distributions are plotted in Fig.1 (a). The critical density surface is located at x=4.8 μm which is close to the point where the current density is zero. The return current flows inside the critical surface, and surface current flows in front of it. The surface acceleration becomes effective, only when the magnetic field dominant region is separated from the electric field dominant region. The magnetic field tends to reflect electrons towards the vacuum side, and electric field tends to turn back electrons towards the target side. Thus these electric and magnetic fields tend to keep electrons around the critical surface. In other words, electrons are confined inside the potential well of the electrostatic potential and vector potential. When electrons are confined in a potential well, they oscillate around the bottom of the potential. Since there also exists an oscillating laser field, electrons effectively absorb energy from the laser field when these two periodic motions are in resonance. A similar situation was studied in electron acceleration inside a laser channel created in gas plasmas, which is called betatron acceleration [3]. Since the laser field is a driving field in surface acceleration, the acceleration length is limited to the laser spot size, which limits the electron energy up to tens of MeV with PW class lasers.

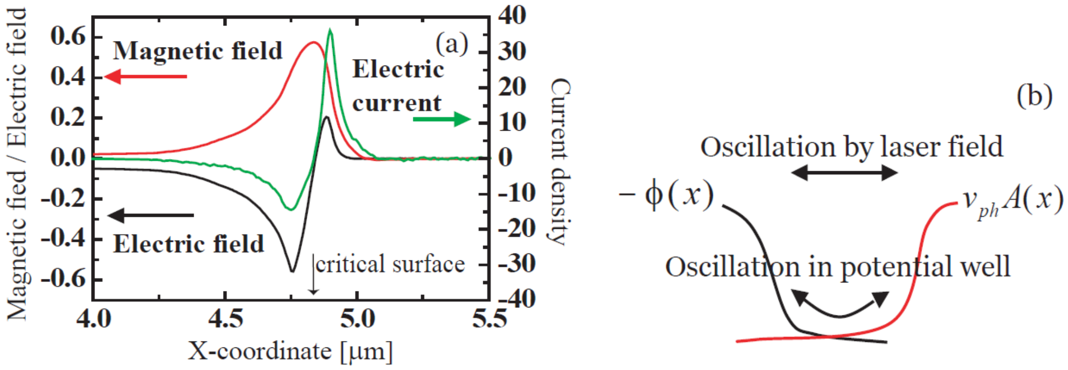

Fig.1 (a) Spatial profile of the surface fields for 75 degree incidence case, which is a transverse cut at y=2.59mm. The electric field and magnetic field are normalized by the laser electric and magnetic fields, respectively. The electric current density is normalized by n_c. (b) A schematic figure showing the surface acceleration mechanism. Electrons perform an forced oscillation by laser electric field inside the potential well.

3. High energy electron generation by surface acceleration using capillary targets

Since the laser intensity depends upon the spot size for a given laser power, the laser intensity and interaction length do not independently increase if the interaction length is limited to the spot size. In order to increase the interaction length without loosing laser intensity, a capillary type target is proposed. Laser propagation well beyond the Rayleigh length is confirmed inside a discharge capillary or solid capillary, and electron acceleration is observed where a plasma wakefield is excited. Surface acceleration is considered to be an alternative way to obtain high energy electrons by using a vacuum capillary [4]. The simulation geometry is shown in Fig.2(a). The target density is 50 n_c, the preplasma scale length is 0.1 μm, and the electron temperature is 1 keV. Laser pulses irradiate the target from the left boundary whose intensity is 1.1×10^{20} W/cm^2. The pulse duration is 150fs. A quasi-static magnetic field is observed along the capillary wall where the laser interacts with the target, which is shown in Fig.2 (b). Figure 2(b) indicates that the surface quasi-static electromagnetic fields are built up, and the electrons are confined and flow along the target surface. The distribution of laser field at the same time is plotted in fig.2(c). The laser propagation which is much longer than Rayleigh length is achieved, which results in elongating the acceleration length of surface acceleration.

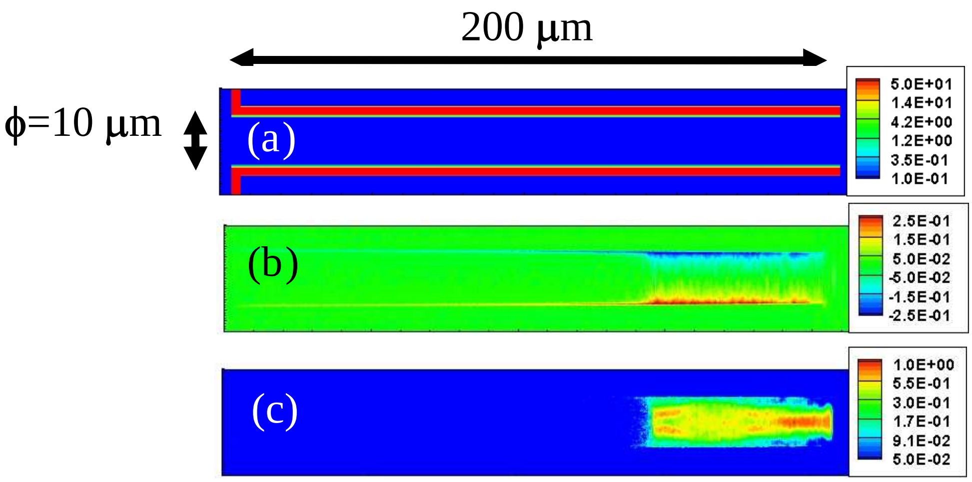

Fig.2 (a) Density profile of the capillary target, which is normalized by the critical density. (b) Distribution of quasi-static magnetic field which is normalized by laser magnetic. (c) Distribution of laser field at t=700fs, which is normalized by laser

The electron energy distribution along the longitudinal coordinate is plotted in fig.3. Electrons are accelerated by the laser field and surface field, which are localized where laser pulse exist. During the propagation of 200 μm, electrons are accelerated up to 300 MeV, which results in the acceleration gradient of about 1.5 TV/m which is about 1/15 of laser electric field.

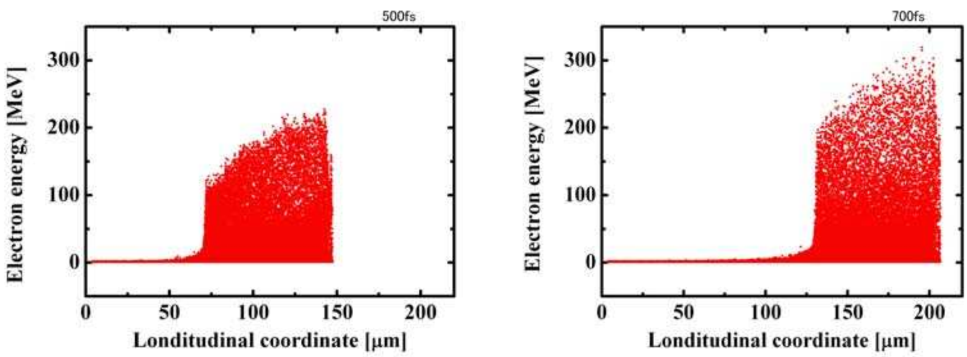

Fig.3 Electron energy distribution along longitudinal coordinate at t=500, and 700fs. Electrons are accelerated together with laser pulse, and gain energy up to 300 MeV

4. Summary and discussions

It is necessary to form surface magnetic field to utilize surface acceleration. The conditions for the formation of the surface magnetic field is 1) laser intensity is in the relativistic regime, 2) laser irradiation angle is larger than 70 degree, and 3) preplasma scale length is smaller than the laser wavelength. The first and third conditions ensure that $J \times B$ heating becomes a dominant acceleration process which generates high energy electrons being well collimated towards the laser irradiation direction. When these conditions are satisfied, surface magnetic and electric fields are generated and the surface acceleration takes place.

In conclusions, we presented the surface acceleration which takes place when a quasi-static magnetic and electric fields are induced on the laser irradiation surface and showed that the surface acceleration is effective in a capillary target. In surface acceleration the electron periodic motion in a potential well is in resonance with the laser oscillating electric field, which leads to electrons acceleration by the laser field. Since the interaction between the electrons and the laser fields continues for many laser periods, the effective temperature is not limited to the ponderomotive energy. A capillary target is able to lengthen the interaction length without loosing the laser intensity, which leads to the generation of very energetic electrons by the surface acceleration process. Electrons are accelerated up to about 300 MeV by irradiating laser pulse whose intensity is 1.1×10^{20} W/cm^2 and capillary length of 200 μm. The corresponding acceleration gradient is 1.5 TV/m which is about 1/15 of the laser electric field.

Acknowledgments

Authors thank James Koga for useful discussion. This work is performed under the grant-in-aid of science research foundation No. 15GS0214, and in part under the grant-in-aid for young scientists (B) No. 18740351, and by the support of the Computation Group at ILE, and the ITBL project at JAEA.

References

[1] T.Nakamura, S.Kato, H.Nagatomo, and K.Mima, Phys. Rev. Lett. 93, 265002, (2004).

[2] T.Nakamura, K.Mima, H.Sakagami, and T.Johzaki, Phys. Plasmas 14, 053112 (2007).

[3] A.Pukhov, Z.M.Sheng, and J.Meyer-ter-Vehn, Phys. Plasmas 6, 2847 (1999).

[4] Y.Kitagawa, Y.Sentoku, S.Akamatsu, et al., Phys. Rev. Lett. 92, 205002 (2004).