§35. Suppression Effects of Weibel Instability for Fast Electron Divergence

Sakagami, H.,
Johzaki, T. (Hiroshima Univ.),
Taguchi, T. (Setsunan Univ.),
Mima, K. (Inst. of Laser Engineering, Osaka Univ.)

The FIREX-I project aims to demonstrate that the imploded core could be heated up to 5keV. Efficient core heating mechanisms and achievement of such high temperature have not been, however, clarified yet, and we have been promoting the Fast Ignition Integrated Interconnecting code (FI^3) project to boldly explore fast ignition frontiers.[1-3] First series of the incorporated FIREX-I experiments was performed in 2009, and only 30-fold enhancement in neutron yield was achieved and lower energy coupling from the heating laser to the imploded core was anticipated.[4] According to 2D PIC simulations, it is pointed out that fast electrons which are generated by interactions between the heating laser and the Au cone tip have a large divergence angle (~90 degree), and a tiny fraction of them can hit the target core for heating.[4]

The Weibel instability[5,6] is invoked by fast electron streams produced by the laser pulse and return flows carried by background electrons, which are induced to maintain current neutrality. These oppositely directed currents repel each other, making the distribution of the current density in the transverse direction. It generates large quasi-stationary magnetic fields transverse to the direction of fast electron stream, and the field grows to more than hundred Mega Gauss, which is large enough to scatter several MeV electrons within 1μm. The linear growth rates of the Weibel instability for different background electron temperatures[7,8] are shown in Fig. 1 for n_{fast}:n_{back}=1:9, T_{fast}=100keV and γ_{fast}=9.5. Higher temperature leads to lower growth rate and longer wavelength that gives maximum growth. To check this characteristic, the Weibel instability is investigated with the use of 2D PIC code. In simulations, the Au (A=197, Z=30) cone tip is introduced as a 10μm thickness, 6μm wide, 20n_{cr} flat profile with the preformed plasma, which has a exponential profile of the scale length (L_{pre}=0.5μm) with density from 0.1 up to 20n_{cr}. Initial temperature of electrons is set to 1, 10 or 100 keV, and immobile ions are used to ignore surface deformation effects. The heating laser is set to λ_L=1.06μm, I_L=10^{20}W/cm^2, τ_{rise}=5fs, τ_{flat}=∞. It is confirmed that higher background temperature leads to slower growth of the Weibel instability and smaller divergence angle of fast electrons. If a specific target structure can be introduced to raise the background electron temperature, suppression effects for fast electron divergence may be expected. As background electrons must flow to neutralize the fast electron current, the flow speed of background electrons increases according to decrement of background electron density. This flow excites a strong two-stream instability, which can heat up background electrons.[1] Therefore, we introduce the density trough, which is 10n_{cr} and 0.5μm thickness, into the target. With this target, it is observed that background electrons are heated up more than 100 keV. The Weibel instability is, however, enhanced by the strong flow of background electrons. As a result, fast electron divergence is getting worse and this structure does not work well.

As the growth rate of the Weibel instability is absolutely large, little suppression effects can be expected even if the background electron temperature increase more than 100 keV. The Weibel magnetic field does not remain at rest and shows turbulent behaviors, enhancing the divergence of fast electrons. To control the magnetic field location, the punched out target is introduced, where many vacuum holes are punched out (diameter is 0.7μm, distance between each hole center is 1μm) as shown in Fig. 2 (a). As background electrons that carry the return current can only flow the gap among holes because the sheath field prevents them from crossing over the hole, stable magnetic fields are induced, which are shown in Fig. 2 (b). In the punched out target, the divergence angle is improved but the number of electrons is degraded for fast electrons (< 3 MeV) which can efficiently heat the core. Therefore we will perform integrated simulations by FI^3 to evaluate the core heating performance of this target structure.

This work was partially supported by JSPS Grant-in-Aid for Scientific Research (C)(22540511).

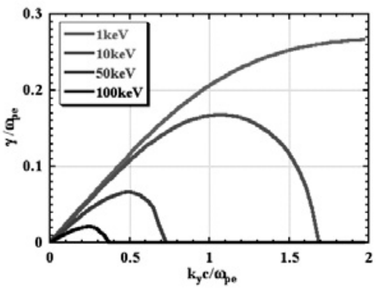

Fig.1. The linear growth rates of the Weibel instability.

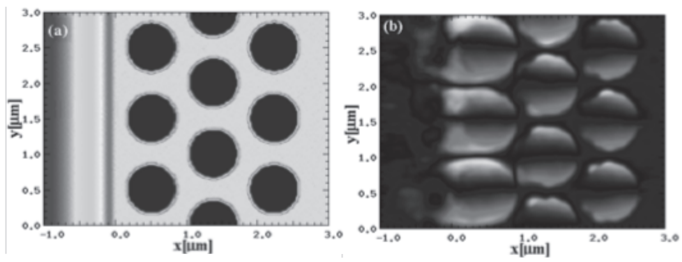

Fig.2. Punched out target. (a) electron density profile and (b) quasi-stationary transverse magnetic field profile.

1) Sakagami, H., et al.:Laser Part. Beams **24** (2006) 191.
2) Johzaki, T., et al.:Laser Part. Beams **25** (2007) 621.
3) Sakagami, H., et al.:Nucl. Fusion **49** (2009) 075026.
4) Johzaki, T., et al.:Nucl. Fusion **51** (2011) 073022.
5) Weibel, E. S.:Phys. Rev. Lett. **2** (1959) 83.
6) Califano, F., et al.:Phys. Rev. E **56** (1997) 963.
7) Sentoku, Y., et al.:Phys. Plasma **7** (2000) 689.
8) Taguchi, T., et al.:Phys. Rev. Lett. **86** (2001) 5055.