

Effects of strong external magnetic field on high-intense laser propagation into dense plasma

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1. Introduction

The establishment of method for generating kilo-tesla class magnetic field using high-power laser allows us to perform experiments of high-intense laser plasma interactions (LPI) under strong external magnetic field [1,2]. Such strong magnetic field affects not only fluid dynamics but also fast electrons and laser propagation. Recently, it is proposed that fast electrons of which divergence is very large are guided by kilo-tesla class external magnetic field and heat core efficiently, and related experiments have been intensively performed [3,4]. With recent progress of strong magnetic field generation in laboratory, fundamental studies using such strong magnetic field have been performed and high-intense laser plasma interactions under strong magnetic field have been opened up as new research area. In this study, we pay attention to high-intense laser propagation into dense plasma under strong magnetic field and have conducted two-dimensional Particle-In-Cell (PIC) simulations of high-intense LPI with strong magnetic field.

2. Simulation condition

Initial electron density profile of target plasma is shown in Figure 1. The target plasma is made of hydrogen and its density profile in x direction consists of preplasma which has exponential profile with scale length of 20 μm and flat plasma with electron density of $40n_{\text{cr}}$, where n_{cr} indicates the critical density. The density profile in y direction is uniform. Applied external magnetic field along the direction of laser propagation, namely x direction, is set to 50 kilo-tesla. Linearly polarized laser that has temporally flattop and spatially Gaussian profiles with spot diameter of 20 μm irradiates the target with normal incidence. At least 500 fs of simulation has been done using 2D PIC code.

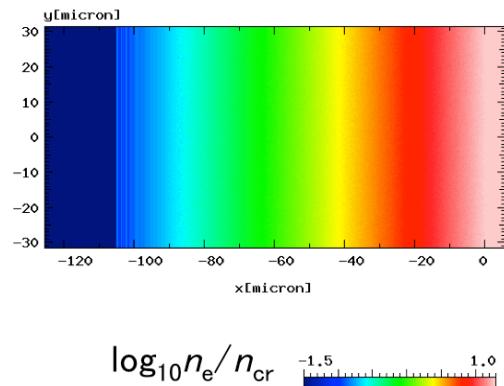


Figure 1. Spatial profile of initial electron density.

3. Laser propagation into magnetized high-dense plasma

Figure 2 shows two-dimensional spatial profiles of (a) averaged intensity of electric field and (b) electron density at (1) 200, (2) 300, (3) 400, and (4) 500 fs. The classical critical density of no magnetic field case, where the considered electromagnetic field cannot propagate, is placed at around $x = -60 \mu\text{m}$. Considering the relativistic correction due to the relativistic laser intensity, the relativistic critical density becomes almost two times larger than classical one and the position of such a density is placed at around $x = -46 \mu\text{m}$. Applying extremely strong external magnetic field, laser can penetrate not only classical critical density but also relativistic critical density as shown in figure 2 (a-2). In addition, some component of injected laser is reflected at around $x = 24 \mu\text{m}$ and other component penetrates over this region. At this position, corresponding electron density is $6n_{\text{cr}}$. According to the linear theory of cold plasma in strong magnetic field, right-handed circularly polarized (RCP) component of electromagnetic wave propagates into dense plasma without critical density (cut-off density) and left-handed circularly polarized (LCP)

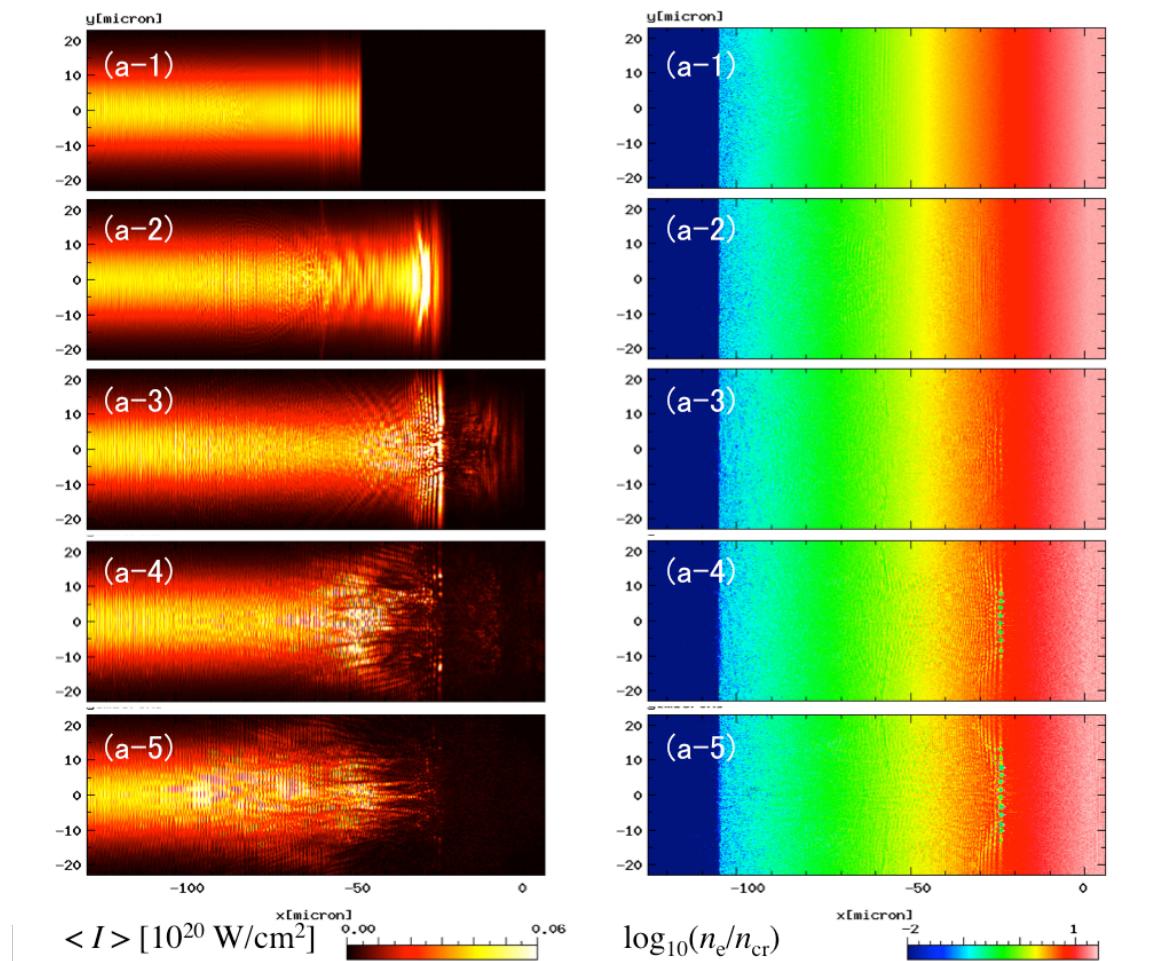


Figure 2. Two-dimensional spatial profiles of (a) averaged intensity of electric field and (b) electron density at (1) 200, (2) 300, (3) 400, and (4) 500 fs.

component has L-wave cut-off density of $6n_{cr}$ in the case of 50 kilo-tesla magnetic field [5]. Simulation results mostly agree with the linear theory, but following laser pulse cannot propagate high density region as shown in figure 2 (a-4,5). This inhibition of RCP component propagation is not expected in the linear theory of cold plasma. It is found that strong ion acoustic wave generates at the area where laser cannot propagate and it triggers the reflection of the RCP component of the injected laser.

4. Laser propagation into weakly magnetized high-dense plasma

Furthermore we have performed additional simulations of weak magnetic fields of 0, 0.5, and 5.0 kilo-tesla. Figure 3 shows two-dimensional spatial profiles of (a) averaged intensity of electric field and (b) electron density in the case of (1) 0, (2) 0.5, and (3) 5.0 kilo-tesla. Simulation result of 0.5 kilo-tesla case is almost same as that of no magnetic field case. In the case of 5.0 kilo-tesla, the filament structure of laser field tends to stretch straight along the direction of external magnetic field and simultaneously the structure on electron density profile also tends to extend straight because the external magnetic field inhibits the motion of electron perpendicular to the direction of the external magnetic field. Figure 4 shows

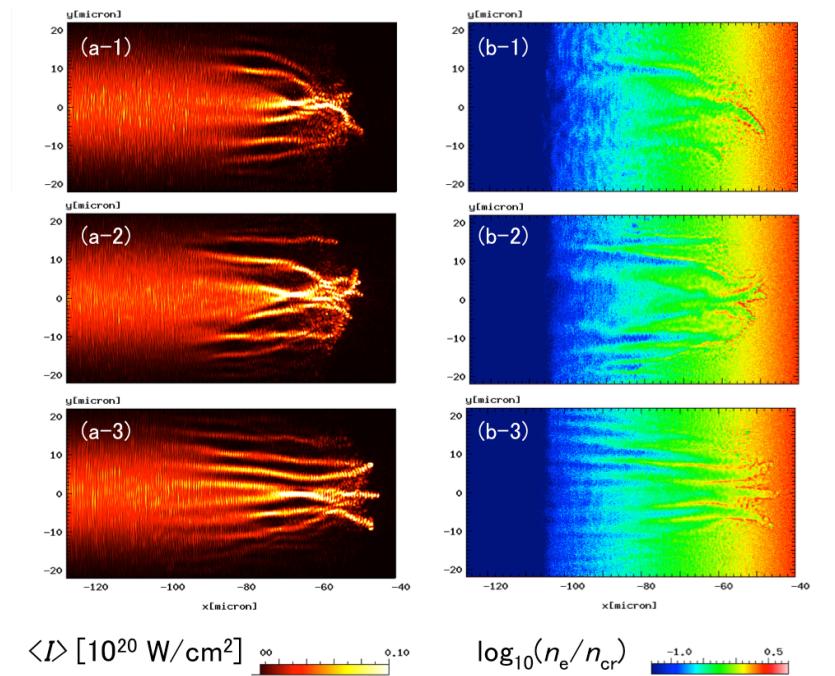


Figure 3. Two-dimensional spatial profiles of (a) averaged intensity of electric field and (b) electron density in the case of (1) no magnetic field, (2) 0.5, and (3) 5.0 kilo-tesla.

two-dimensional spatial profiles of quasi-static magnetic field in x direction for the external magnetic field of (a) 0.5 and (b) 5.0 kilo-tesla, where the magnetic field is averaged over laser period. The structure formation is also observed in the magnetic field profiles. Inside the filament, electrons are expelled and magnetic field is weakened. In contrast electrons are piled up and magnetic field is compressed outside the filament. As a result, magnetic

field is strengthened three times larger than the initial external magnetic field for 0.5 kilo-tesla case and 1.5 times larger for 5.0 kilo-tesla case.

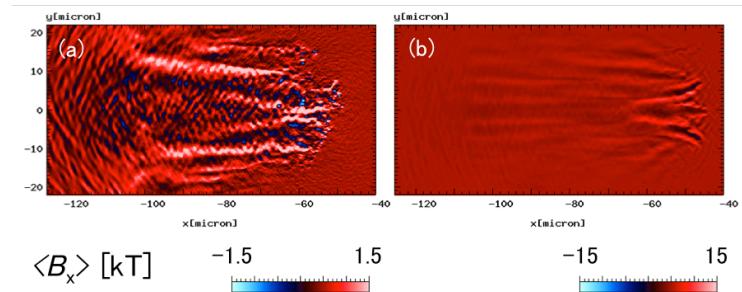


Figure 4. Two-dimensional spatial profiles of quasi-static magnetic field in x direction for (1) 0.5 and (2) 5.0 kilo-tesla cases. The magnetic field is averaged over laser period.

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