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Suppression of Weibel Instability of Relativistic Electron Beam by Strong Magnetic Field

相対論的電子ビームのワイベル不安定性の観測と強磁場による抑制

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Growth of Weibel instability encumbers stable propagation of relativistic electron beams generated by interaction between intense laser and matter. Weibel instability is suppressed by application of external strong magnetic field. Kilo-tesla magnetic field can be generated by using laser-driven capacitor-coil target. We have designed experimental setpup to verify the suppression scheme of Weibel instability by using a gaseous target and laser-driven capacitor-coil targets.

1. Introduction

Weibel instability is driven by an anisotropy of particle velocity distribution in a plasma. Deflection of electrons by non-uniform magnetic field disturbs spatial distribution of currents, and the disturbed current amplifies the non-uniform magnetic field [1,2]. With growth of the instability, complex structure appears due to the coalescence of filament currents. The generation and amplification of the magnetic field due to Weibel instability in a collisionless plasma is studied [3]. In the fast ignition scheme, stable propagation of relativistic electron beam to a fuel core is essential for realization of efficient heating. Growth of Weibel instability encumbers stable propagation of REB in a plasma.

2. Suppression of Weibel Instability

Weibel instability can be suppressed by applying external strong magnetic field in the direction of REB propagation. Return current flows to neutralize the huge electric currents carried by the REB. Velocity of electrons in the return current is relatively slow, and the slow electrons are trapped by the external magnetic field, and thus the return current is guided by the external magnetic field. Current density non-uniformity does not grow in this situation, and Weibel instability is suppressed. This effect is governed by the ratio of ω_c/ω_p in a plasma, here ω_c and ω_p are electron- cyclotron and electron-plasma frequencies, respectively. A strong magnetic field generated by a laser-driven capacitor-coil target allows us to create the condition of $\omega_c/\omega_p \sim 1$ in the laboratory. Hybrid simulation shows stable laminar flow of REB at $\omega_c/\omega_p \sim 1$.

3. Proposal of experimental set up

3.1 Generation of REB and magnetic fields

Figure 1 shows an experimental setup to observe growth of Weibel instability in strong magnetic field. Helmholtz-type coils generate spatially uniform and strong magnetic field. Solid planar targets are put between the coils, gas is filled between the plates. REB is generated by interaction between the solid plate and intense laser beams, and the REB propagates through the magnetized gas. Trajectories of filament currents in the gas appear as density fluctuations of the gas. Schlieren imaging is used to visualize structure of the REB in the magnetized gas.

400 T of magnetic field strength can be obtained by using Helmholtz-type two capacitor-coil targets. Electron-cyclotron frequency corresponding to 400

T is ω_c = 7 x 10^{13} rad/s. Density of the gas is 1.5 x 10^{18} cm^{-3}, and its electron-plasma frequency is ω_p = 7 x 10^{13} rad/s. Condition of ω_c/ω_p ~ 1 can be produced in the laboratory with this set-up.

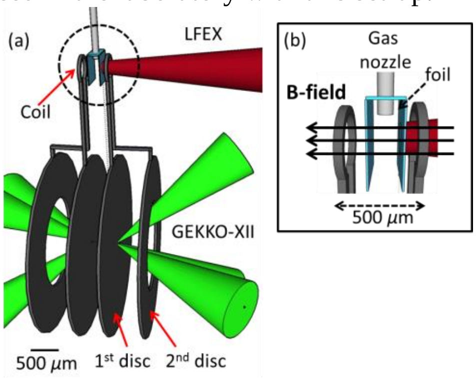

Fig.1 Schematic drawing view of experimental set-up. (a) Two capacitor-coils are set in parallel. A strong magnetic field pulse (B = 400 T, ω_c = 7 x 10^{13} rad/s) is generated between the coils. (b) REB is generated by interaction between the solid plate and intense laser beams, the REB propagates through the magnetized gas ($n_e = 1.5\times10^{18}$ cm^{-3}, $\omega_p = 7\times10^{13}$ rad/s). Trajectories of current filaments in the gas appear as density fluctuations of the gas.

3.2 Development of the probe laser system

(a)

(b)

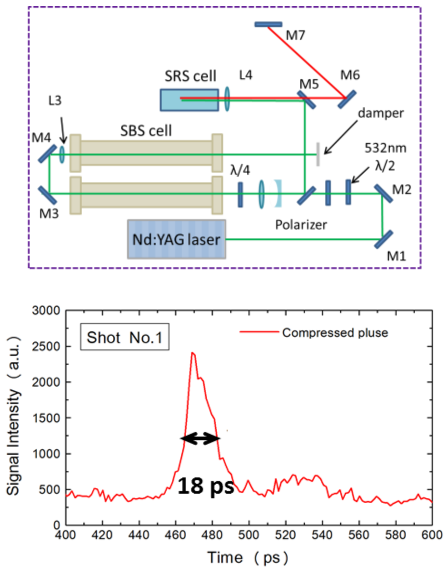

Fig.2 (a) Setup of a 20 ps probe laser pulse generation utilizing SBS and SRS pulse compression schemes. Laser pulse with 532 nm of wavelength and 7 ns of duration is compressed down to 300 ps in the SBS cell. The 300 ps pulse is compressed again down to 20 ps in the SRS cell. Wavelength of the laser is changed to 630 nm by the Raman scattering. (b) Temporal profile of the compressed pulse.

Lifetime of density fluctuations induced by filament currents is less than 100 ps. Duration of probe laser pulse must be a few tens ps for observing clear structures of the density fluctuations. We developed a 20 ps probe laser pulse by combining two pulse compression schemes (stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS) [6,7]). Figure 2 shows experimental setup for pulse compression.

4. Summary

A strong magnetic field generated by a capacitor-coil target allows us to verify the suppression of Weibel instability in the laboratory. We designed experimental setup for this purpose. Short pulse probe laser was developed to obtain clear schlieren image of filament currents that flow in a magnetized gas. This experiment will be performed in GEKKO-LFEX laser facility in this fiscal year.

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