23A01

Collisionless shock experiments using high-power laser systems
高出力レーザーを用いた無衝突衝撃波生成実験

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High-mach number collisionless electrostatic shocks have been produced in counter-streaming plasmas using high-power laser systems; Shenguang II [T. Morita et al., Phys. Plasmas 17, 122702 (2010)] and Gekko XII [Kuramitsu et al., Phys. Rev. Lett. 106, 175002 (2011)]. In order to demonstrate the formation of collisionless shocks through the self-generated magnetic field due to the nonlinearity in the growth of the Weibel instability, we applied to use the NIF facility, and it was approved as a three-year experiment. OMEGA and OMEGA EP experiments have been started to study the plasma conditions of counter-streaming plasmas using Thomson scattering and to develop proton radiography diagnostics.

1. Introduction

Collisionless shocks are often observed in space and astrophysical plasmas. Large amplitude turbulent waves and energetic particles are also observed in the shock environments. Diffusive shock acceleration is considered to be a standard model for non-thermal acceleration of energetic particles or cosmic rays in the universe. On the other hand, in astrophysical plasmas, there is no way to directly measure the key quantities to investigate the shock dynamics and the particle acceleration. One can observe the X-ray emission from the vicinity of the shock-front; however, there are significant uncertainties in the physics surrounding particle acceleration by collisionless shocks. A laboratory experiment can be an alternative approach to study collisionless shocks and particle acceleration.

In this paper we investigate laboratory experiments to study collisionless shock generation in counter-streaming plasmas using high-power laser systems.

2. Numerical studies

Recent numerical and particle-in-cell (PIC) simulation studies show that there are two possible collisionless shocks in unmagnetized plasmas: One is an electrostatic (ES) shock [1,2], and the other is a Weibel-mediated shock in self-generated magnetic field [3]. A scaling-law derived by changing flow velocities and ion-electron mass ratio in 2D PIC simulation revealed that a high-density (electron density $n_e \sim 10^{20}$ cm^{-3}), high-flow velocity ($v \sim 1000$ km/s), and large volume (plasma length ~ 30 mm) plasmas are required to produce Weibel shock. In order to achieve these plasma parameters, NIF-class laser system is required.

3. Experiment

Under international collaborations, we have performed several series of experiments on the high-mach number collisionless ES shock formations using Shenguang II laser system in China [4] and Gekkko XII HIPER laser system at Osaka Univ. [5].

In Gekko XII experiment [352 nm (3ω), 500 ps, ~100 J/beam, one to four beams, < 10^{15} W/cm^2], in order to produce collisionless counter-streaming plasmas, a plastic (CH) double-plane target (60 μm in thickness and 4.5 mm in separation) was irradiated by laser beams onto the inner side of the 1st CH plane [6]. A laser-ablated plasma is formed at the 1st CH, and the 2nd CH plasma is created by radiation and/or the plasma from the 1st CH. The plasmas and shocks were diagnosed transverse to the main laser propagation direction; shadowgraphy and interferometry using a probe laser [Nd: YAG laser, 527 nm (2ω), ~10 ns] with ICCD and streak cameras, and visible (450 nm) self-emission measurements with ICCD and streak cameras.

Counter-streaming plasmas were produced, and we successfully observed ES shock structures by shadowgraphy and self-emission [6].

In order to demonstrate the formation of collisionless shocks through the self-generated magnetic fields due to the nonlinearity in the growth of the Weibel instability, we have applied to the NIF facility time proposal 2010 (PI: Y. Sakawa). It was approved as a three-year experiment, and the experiment will be conducted from probably 2013 when the required diagnostics, for example optical interferometry, are constructed.

We started OMEGA and OMEGA EP experiments [PI: H.-S. Park (LLNL) and PI: A. Spitkovski (Princeton Univ.)] to study the plasma conditions of counter-streaming plasmas using Thomson scattering and to develop proton radiography diagnostics for the Weibel-filaments, self-generated magnetic field, and shock-structure measurements. In the OMGA experiment, 10 laser beams (1 ns, 500 J / beam, ~10^{16} W/cm^2) were focused on each plane of CH double-plane target with 8-mm separation. It was demonstrated using Thomson scattering measurements that a plasma with $n_e \sim 10^{19}$ cm^{-3} and $v \sim 1000$ km/s was created at 4 mm from the target (middle of the two CH planes) at ~5 ns form the laser timing. Proton radiography using OMEGA EP laser with two long-pulse beams for counter-streaming plasma production [352 nm (3ω), 3 ns, ~2.2 kJ/beam] and two short-pulse beams for two-channel proton radiagraphy [1.05 μm (ω), 10 ps, 250 J/beam] showed intersting filamentary and shock-like structures.

4. Summary

Collisionless shocks are studied in counter-streaming plasmas using high-power laser systems. Weibel-mediated shock experiment will be conducted with NIF laser system in near future.

Acknowledgments

A part of the experiments was performed under the joint research project of the institute of laser engineering, Osaka University, and supported by Grant-in-Aid for Scientific Research (B), MEXT of Japan (No. 21340172), and by a grant for the Core-to-Core Program from the Japan Society for the Promotion of Science (JSPS).

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