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Collisionless shock generation in an external magnetic field by using high-power laser system
高出力レーザーを用いた磁場中における無衝突衝撃波の生成

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Collisionless shocks are produced in counter-streaming plasmas in an external magnetic field.The shocks are generated due to an electrostatic (ES) field generated in counter-streaming laser-irradiated plasmas, whose resuls have been reported previously in a series of experiments without external magnetic field [T. Morita *et al.*, Phys. Plasmas, 17, 122702 (2010), Kuramitsu *et al.*, Phys. Rev. Lett., 106, 8 (2011)] via laser-irradiation of a double-CH-foile target. The magnetic fields are generated by putting an electro-magnet ($\sim$10 T and $\beta \sim 10^{1-4}$) near the target. The result shows no large difference between with and without external magnetic field in high β condition early in time ($t < 25$ ns).

1 Introduction

The aim of the research is to reproduce collisionless shocks as observed in supernova remnants (SNRs) and to find the physics of collisionless shock formation. This also aims at the physics of particle acceleration relating to the origin of cosmic rays. We have studied collisionless shock with high-power laser-produced counter-streaming plasmas[1, 2]. These results have shown high Mach-number electrostatic (ES) shock generation in high-speed counterstreaming laser-produced plasmas. In the universe, usually, electromagnetic shocks are observed at SNRs, however, the ES shocks can be produced in a very early stage of the growth of SNRs. These experiments, however, have been performed without an external magnetic field. In this report, we show the collisionless shock generation with an external magnetic field in which the plasma beta is relatively high ($\beta \sim 10^{1-4}$ at $t < 25$ ns after laser irradiation) and is comparable to those of typical SNRs ($\beta \sim 10^{3-6}$).

2 Experiment

The experiment was performed with Gekko-XII HIPER laser system, frequency tripled Nd:Glass laser (351 nm) which have the energy of $\sim$ 120 J/beam in 500 ps with the focal spot of 300 μm in diameter and the intensity of 10^{15} W/cm^2 to produce high-velocity counter-streaming plasmas. Three laser pulses are focused on one of the inner surface of a double-CH-foil target (first-foil) as shown in Fig. 1 to produce high-velocity plasma flow. The other foil (second-foil) is irradiated by the radiation from the plasma generated at the first-foil, resulting in the generation of counter-streaming plasmas between two foils. The plasmas are diagnosed with a streaked-optical pyrometer (SOP) and self-emission gated-optical-imager (GOI) by observing the emission, and the shadowgraphy (SG), interferometry (IF), and the measurement of Thomson sattering (TS) using a probe laser: frequency doubled Nd:YAG laser (527 nm) with the pulse duration of ∼20 ns and an intensified charge coupled device (ICCD) with 2 ns exposure time. An electro-magnet is placed at ∼5 mm from the edge of the target to apply an external magnetic field of ∼10 T perpendicular to the target normal direction.

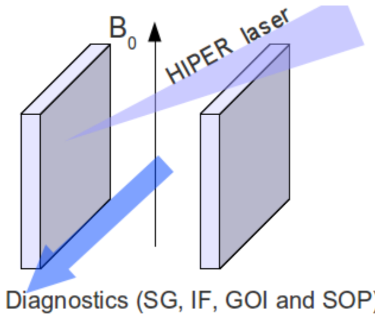

Figure 1: The schematic view of the target. HIPER laser pulses are focused on the inner surface of the first foil. The magnet is placed near the target to produce an external magnetic field perpendicular to the target normal direction.

3 Result

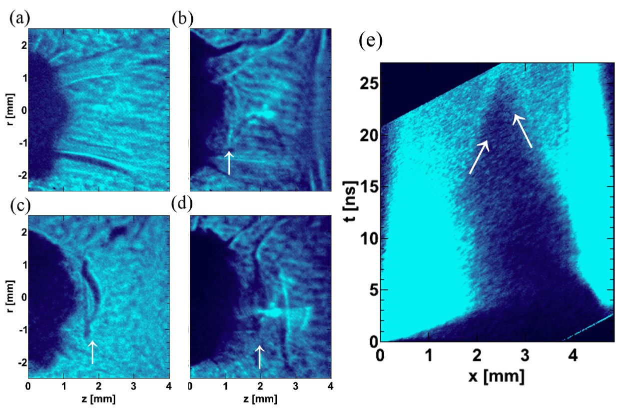

Figure 2: The SG data taken at (a) $t = 10$ ns, (b) 15 ns, (c) 20 ns, and (d) 25 ns, and (e) the SOP with external magnetic field of ~ 10 T. The data of [(a) and (c)] and [(b), (d), and (e)] are taken in the same laser shots.

Figures 2(a)–2(d) show the SG data taken at $t = 10$, 15, 20, and 25 ns, respectively, with an external magnetic field of ~ 10 T applied by the electromagnet. Early in time at $t = 10$ ns, there are no density jump observed by the SG, however, the clear shock image can be obtained at later time as shown with white arrows in Figs. 2(b)–2(d). The SOP data shows the time evolution of the plasmas as shown in Fig. 2(e). The data of Figs. 2(b), 2(d), and 2(e) are taken in a same laser shot. Two shocks are observed as shown with white arrows after $t = 20$ ns. In our previous result argued in Ref. [1, 2], these shocks are generated by ES potential comparing with the shock width and formation time of them with numerical calculations[3] of particle-in-cell simulations. More later in time ($t > 25$ ns), two shocks interact each other and and propagate in different directions (not shown in this report).

Comparing the experimental results with and without external magnetic field at relatively early in time ($t < 25$ ns), there are no large difference in shock formation time and shock velocities combining the results of the GOI, IF, and SOP. Later in time ($25 < t < 60$), the velocity of two shocks are different between with and without a magnetic field.

4 Conclusion

We have produced ES shocks in counter-streaming laser-produced plasmas in an external magnetic field. The density jumps due to the ES shocks are clearly observed in the SG and SOP as in Fig. 2, IF, and TS (not shown). Comparing the results with and without an external magnetic field, there are no large difference in relatively large $\beta \sim 10^{1-3}$ at early in time ($t < 25$ ns).

Acknowledgments

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