論文 / 著書情報
Article / Book Information

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Title(English)	An Experimental Approach to Astrophysical Phenomena using Interacting High-Speed Plasma Flow
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Astrophysical phenomena relevant to the interaction of high-speed plasma flows are ubiquitous in the space. The high-speed plasma flows are involved in the escape of planet atmosphere, the formation of bow shocks in front of magnetosphere, particle acceleration in shock waves, and magnetic reconnection. In particular, high energy particles accelerated in shock waves formed in supernova remnants are considered to be main sources of cosmic rays. In the shock waves, the kinetic energy of the plasma flow dissipates through generation of electric field and/or compression of magnetic field, even in collisionless conditions. The dissipation process in the collisionless plasma is considered to depend strongly on plasma parameters, which makes it difficult to investigate the astrophysical shock waves only by observations using telescopes and satellites. Hence, parametric studies with laboratory scale device are needed to well understand the dissipation process of collisionless shocks.

As an approach to study the mechanism of collisionless shock formation, laboratory astrophysics has been attracting great attention since 1960s. In the previous studies, several types of plasma sources were used for laboratory astrophysics experiments. They are laser ablation plasma sources, coaxial plasma guns, z-pinch devices, plasma focus devices, and wire array discharge devices. Recently, in the plasma interaction experiments with a counter-streaming configuration using high-intensity lasers or plasma gun and related PIC simulations, have arisen much interest in the field of laboratory astrophysics. Interaction experiments using counter-streaming configuration are useful for systematic study on collisionless shock waves over a wide range of parameters of plasma flows. However, these plasma sources are not so suitable to the parametric study because of their large stored energy and low capability of repetitive operation. A well-defined plasma source with high reproducibility and controllability is needed to perform the parametric study.

In this study, we proposed a new type of plasma source using tapered z-pinch discharge in a thin tapered capillary to investigate the complicated dissipation processes arising in interacting high-speed plasma flows and constructed a table-top experimental apparatus based on a counter-streaming configuration of the taper pinched plasma source (TPPs). We revealed the potential as a device for investigating the formation process of plasma shock waves. We focused on ion acoustic Mach number and mean free path for ion-ion collision as scaling parameters relevant to shock waves in unmagnetized plasma. Mach number is generally the most important parameter to characterize shock waves accompanying with high-speed plasma flows. Shock waves in the astrophysical objects such as high-speed plasma flows interacting with planet magnetosphere and supernova remnants, typically have the ion acoustic Mach numbers of order of 10.

The TPP was radially compressed and axially accelerated by a sequentially pinching current sheet. A high-speed plasma with a Mach number of 10 under a collisionless condition of ion-ion was successfully obtained using the thin tapered capillary filled with argon gas.

A differential pumping system and a dual-stage pre-ionization circuit were adopted to improve the reproducibility of the tapered z-pinch discharge. To pre-ionize the argon gas weakly, a few kV of DC voltage was applied between the electrodes before triggering the pulsed discharges. The DC pre-ionization prevented localization of the current path of pulsed pre-ionization discharge. The shot-to-shot fluctuations of the peak arrival time and the amplitude of the peak plasma flux were within 20 %, which is enough to conduct the interaction experiments.

We showed that the TPP parameters can be controlled independently by the discharge current, the pre-filled gas density, and the taper geometry. The ion density can be also controlled by the flight distance of the plasma plume because the plasma is freely expanding. We also indicated synchronization of axial motion of plasma and the difference of pinching times of current sheet is a guideline to design the taper geometry.

The TPP was extracted into an interaction chamber through a small aperture of the anode electrode. As the anode aperture prevents diffusion of magnetic field into the interaction chamber, the TPP device can form an unmagnetized plasma flow more easily than conventional z-pinches, θ-pinches, and coaxial plasma guns. The device also enables us to adopt conventional and well-developed plasma diagnostics thanks to moderate spatio-temporal scale of the plasma in the test section.

In conclusion, we established a table-top interaction experimental device relevant to astrophysical phenomena. Preliminary interaction experiments of counter-streaming high-Mach-number flows were carried out with this device under collisionless condition of ions. We evaluated the strength of interaction by comparing ion-current and optical signals from the high-speed plasmas with and without interaction. All of the results indicated that the interacting high-speed argon flows may dissipate almost 20 % of their initial kinetic energy in the interaction region even without ion-ion collisions.