§1. High Density Plasma Experiment: HYPER-I

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High Density Plasma Experiment-I (HYPER-I[1,2]) is a versatile linear plasma device for collaborative research. HYPER-I consists of a cylindrical vacuum chamber (30 cm in diam. and 200 cm in axial length), ten magnetic field coils, and a high power klystron amplifier as shown in Fig. 1. The magnetic field configuration is a weakly diverging one, so called magnetic beach. The plasmas are produced by electron cyclotron resonance (ECR) discharges of various gas species with a right-handed circularly polarized 2.45 GHz microwave injected from the high-field side along the magnetic field line. HYPER-I is capable of producing over-dense plasmas readily, since the excited electron cyclotron wave is not subjected to the density cutoff. One of the advantages of the HYPER-I device is its controllability of plasma density and electron temperature by adjusting three external control-parameters, i.e. the microwave power, the operation pressure, and the magnetic field configuration. The klystron amplifier provides a wide range of microwave power from several dozen W to 80 kW in CW. The gas-introducing system has six mass flow controllers (MFCs), four of which are 1 $_{\mathrm{LM}}$ full scale and the others are 50 $_{\mathrm{SCCM}}$ full scale. The magnetic field configuration can be altered by adjusting the coil positions and current. Thus, HYPER-I can offer a wealth of opportunities for exploring various plasma phenomena

HYPER-I also offers a variety of plasma diagnostics: Langmuir probes, directional Langmuir probes (DLP), emissive probes, magnetic probes, a retarding field energy analyzer, a high-impedance wire grid detector (HIWG) with fast voltage-follower circuits, optical emission spectroscopy, saturated absorption spectroscopy (SAS), laser-induced fluorescence (LIF) Doppler velocimetry, and ICCD imaging. Five relocatable probe-driving systems ensure the flexibility of various probe measurements. The DL750P ScopeCorder (Yokogawa) is available for multi-channel data acquisition up to 16 channels. Two tunable external cavity diode lasers (ECDL) and a 30 Hz tunable pulsed dye laser pumped by an Nd:YAG laser are equipped for LIF measurement of metastable argon neutrals and metastable argon ions. In addition, an image intensified CCD (ICCD) camera with a user-selectable optical band-pass filter enables to perform two-dimensional optical emission imaging.

Research activity of the HYPER-I experiment group covers a wide range of topics from basic plasma physics experiments to the development of novel diagnostics, which provides a unique opportunity to collaborators including many graduate students.

Some of the important achievements in this fiscal year are described below.

(i) *Intermittency in local electron flux*

An intermittent behavior of local electron flux has recently been observed in the HYPER-I device. Statistical analysis base on the probability density function of waiting time revealed that the phenomenon is characterized by the Poisson process[3]. Two-dimensional imaging of the optical emission from excited state of neon neutrals (short living Ne $2p_1$ state at 585 nm) has been conducted using the floating potential on a Langmuir probe as a trigger signal for the ICCD gate timing, which clearly demonstrates a circular region of enhanced excitation due to increase in the effective electron temperature.[4] Line emissions from He I (706 nm) and He II (468 nm) have also been measured. Preliminary estimations from the ICCD imaging results suggest the decrease in background neutral density inside the intermittent electron flux.

(ii) *Development of laser diagnostics*

LIF Doppler spectroscopy is a powerful tool to measure flow structures in plasmas. In-situ wavelength calibration system for the HYPER-I pulsed dye laser system based on a Fabry–Pérot interferometer has been developed in this fiscal year. A promising result has been obtained in an initial experiment that the interferometer signal becomes a one-valued function of the laser wavelength.

In addition, the development of novel plasma spectroscopy using tunable optical vortex (Laguerre-Gaussian mode) laser is now being underway. Particles in the optical vortex laser experience the Doppler effect not only for the propagating direction of the laser but for the transverse direction due to the orbital angular momentum of light[5]. This property may open up completely new possibilities in plasma flow measurement.

1) Tanaka, M. Y. et al.: Rev. Sci. Instrum. **69** (1998) 980.
2) Yoshimura, S. et al.: in preparation for submission to a special issue of J. Plasma Phys., entitled *Experiments at the frontier of fundamental plasma physics*.
3) Yoshimura, S., et al.: JPS. Conf. Proc. **1** (2014) 015030.
4) Yoshimura, S., submitted to IEEE Trans. Plasma Sci.
5) L. Allen et al.: Opt. Comm. **112** (1994) 141.

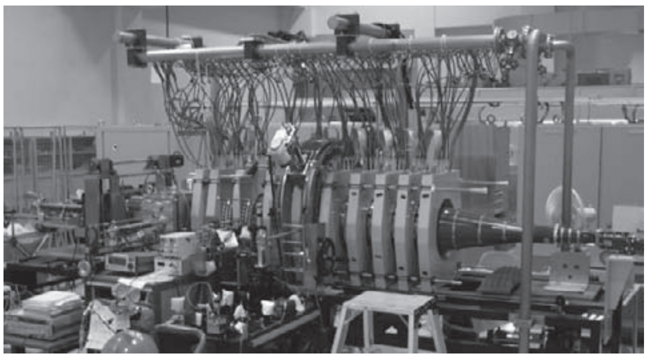

Fig. 1. The HYPER-I device.