§1. High Density Plasma Experiment: HYPER-I

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High Density Plasma Experiment-I[1] (HYPER-I) is a versatile linear electron cyclotron resonance (ECR) plasma device for basic plasma research, which has been in operation for 19 years since 1996 (Fig. 1). A right-handed circularly polarized 2.45 GHz microwave is injected from the high-field side of the device to produce ECR plasmas. This injection method has an advantage that the excited electron cyclotron wave (ECW) is not subjected to any density cutoff. Therefore, the attainable electron density of HYPER-I plasmas exceeds more than two orders of magnitude higher than the cutoff density for ordinary waves. Moreover, various gas species can be used for experiments, because only electron dynamics determines the propagation characteristics (dispersion relation) of ECW. HYPER-I also offers a variety of easy-to-use diagnostics both electrical and optical ones. The combination of a wide operation range of plasma production and flexible diagnostics makes HYPER-I a suitable facility for collaboration research and enables to explore various plasma phenomena.

Main research topics of the HYPER-I experiment group are on spontaneous plasma behavior, which includes flow pattern formation and intermittency[2], and on the development of new diagnostic tools such as a high-impedance wire-grid detector (HIWG[3]) for time-resolved 2D floating potential measurement. The development of novel laser absorption spectroscopy using multi-dimensional Doppler effects of a Laguerre-Gaussian beam (optical vortex) has been fully initiated under the auspices of NINS cross-disciplinary collaboration research program for young scientists. Many optical components including a spatial light modulator (SLM) have been introduced in this fiscal year.

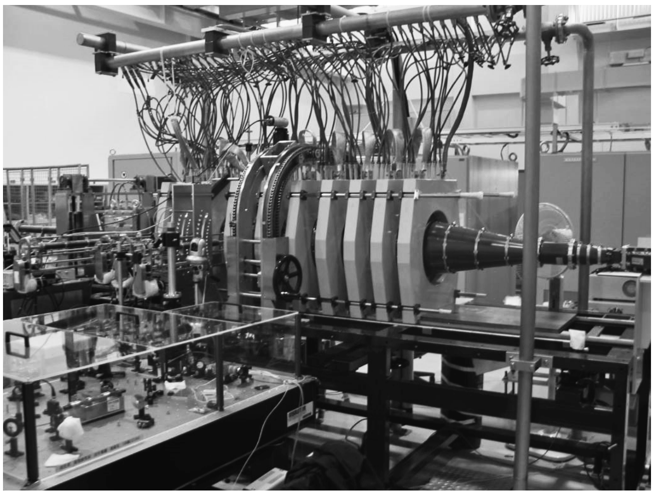

Fig.1 The HYPER-I device

Some of the important achievements of the HYPER-I experiment group are summarized below.

(i) Intermittent change in local electron temperature

Time development of local electron temperature change associated with floating potential intermittency has been observed by means of the conditional averaging method. The duration time of the temperature change was typically 10 μs for helium discharges, and the maximum electron temperature attained was about four times higher than the equilibrium value. This result was confirmed by optical measurement. In usual HYPER-I plasmas, typical electron temperature is about 10 eV. Hence, the He II line emission at 468 nm is not clearly observed due to high excitation energy required for the transition, which is about 51 eV. A circular luminous region has, however, been observed by ICCD imaging with an interference filter under the presence of floating potential fluctuation[4].

(ii) Optical vortex laser system

A tunable external cavity diode laser has been used as the light source for optical vortex creation. The laser wavelength is 696.5 nm, which corresponds to the resonant absorption wavelength of metastable excited ($4s[3/2]^o_2$) state of argon neutral. The optical vortex is created as the first order diffracted light from the computer generated hologram (CGH) depicted on the screen of SLM. The CGH is a bitmap image of the interference pattern of a conventional Hermite-Gaussian beam and a Laguerre-Gaussian beam, which forms a fork-shaped grating. An optical vortex beam having m=1 topological charge[5] has been created successfully in the HYPER-I laboratory.

The Doppler effect for atoms moving perpendicular to the light path of optical vortex is proportional to the topological charge and the velocity of atoms. However it is difficult to create high-quality higher-order Laguerre-Gaussian beams. Instead, a fast gas puffing system using a solenoid valve with a Lavar nozzle, which can produce high-speed neutral flow in a plasma, has been installed on the HYPER-I device. A proof-of-principle experiment for optical vortex Doppler velocimetry using high-speed argon neutral flow is being planned for the next fiscal year. It is promising that applying optical vortex to laser spectroscopy will expand the capability of flow measurement for basic plasma research.

1) Yoshimura, S. et al.: J. Plasma Phys. **81** (2015) 345810204.
2) Yoshimura, S. et al.: IEEE Trans. Plasma Sci. **42** (2014) 2554.
3) Terasaka, K. et al.: Rev. Sci. Instrum. **85** (2014) 113503.
4) Yoshimura, S. et al.: Plasma Fusion Res. **10** (2015) 3401028.
5) Andrews, D. L. and Babiker M. (ed.): *The angular momentum of light*, Cambridge University Press (2013).