§3. Neutral Flow Measurement Using a Tunable Diode Laser

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Large scale flow structure in a plasma is primarily determined by E×B drift. Recently, it has been experimentally found that there exists a class of vortices, which rotate to the opposite direction of E×B drift (referred to as anti-E×B vortices)[1]. The anti-E×B vortices are considered to be driven by the strong interaction between neutrals and ions. The vortices always accompany with a deep density depletion in the background neutrals. Steep density gradient of the neutrals causes a radial flow, which directs to the center of the plasma. When the momentum of neutral flow (inward) is transported to the ions through charge exchange collisions, an inward force arises, and the anti-E×B drift may occur if this force exceeds the electric field (outward).

To understand the effect of neutral flow on the behavior of ion dynamics, we have been developing a high precision LIF Doppler spectroscopic system using a tunable external cavity diode laser. A narrow bandwidth laser is essential for high resolution measurement of the neutral velocity distribution function and the Doppler shift. The system is capable of determining a flow velocity of about 2 m/sec.

The experiments have been performed in the HYPER-I device. The vacuum vessel is 0.3 m in diameter and 2 m in axial length. Plasmas are generated and sustained by electron cyclotron resonance (ECR) heating of argon with the pressure of 10 mTorr. The frequency of microwave is 2.45 GHz, and the input power (P_w) is changed from 40 W (low power operation) to 5 kW (high power operation). The LIF system has been first developed with plasmas in the low power operations, in which the LIF signal is easily detected. The anti-E×B vortex appears in the high power operations.

The schematic diagram of the LIF spectroscopy system is shown in Fig. 1. A diode laser is tuned to a wavelength 696.735 nm and the output beam is introduced into the plasma through the radial port. Metastable argon atoms are excited to an upper energy level ($3s^2 3p^5(^2P^o_{3/2})4s \rightarrow 3s^2 3p^5(^2P^o_{1/2})4p$), and then deexcited by $3s^2 3p^5(^2P^o_{1/2})4p \rightarrow 3s^2 3p^5(^2P^o_{1/2})4s$ transition, emitting fluorescence photons of 826.679 nm, which are detected by a photomultiplier tube (PMT) and a lock-in amplifier. The sub-beam is fed into two optional units; one consists of Fabry-Perot interferometer, whose free spectral range is used as a wavelength scale, and the other is an iodine gas cell. The absorption line of iodine located at 696.7428 nm is used as the wavelength references.

After confirming the presence of metastable atoms, we measured the LIF spectrum at P_w = 40 W. The observed spectrum is quite well fitted by a Gaussian distribution, and the temperature of metastables is 0.034 eV.

Because of depletion of the metastable atoms and increase of background light, the signal to noise (S/N) ratio of the LIF signal considerably decreases in the high power operations. In order to overcome the reduction of the S/N ratio, we have improved the collection optics so as to receive more LIF photons. The solid angle is increased by 5 times, and the modulation frequency f_m is raised up to 100 kHz, which is realized by introducing an electro-optical modulator. The result obtained with the improved optics is shown in Fig. 2. The temperature is found to be 0.12 eV.

Measuring the distribution functions at different points along the horizontal axis, we have found that there exists an inward flow with a maximum velocity of 80 m/sec. The distribution functions (except for r = 0) are slightly asymmetric. This result suggests that the distribution function of the neutrals consists of slow bulk and fast components, which respectively come from the wall and charge exchange collisions with the ions.

In addition to radial flow velocity measurement, azimuthal flow velocity measurement is of importance from the viewpoint of ion-neutral interaction, which is now in progress.

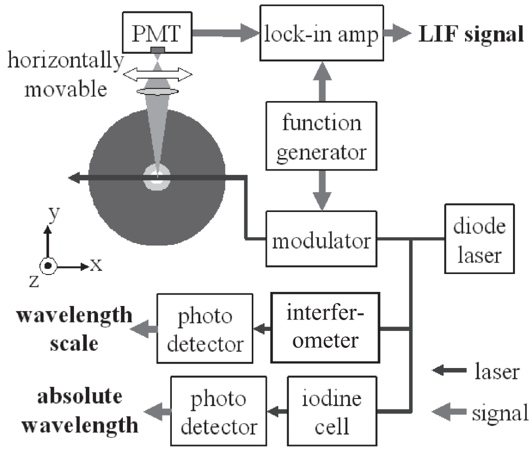

Figure 1 schematic diagram of the LIF system

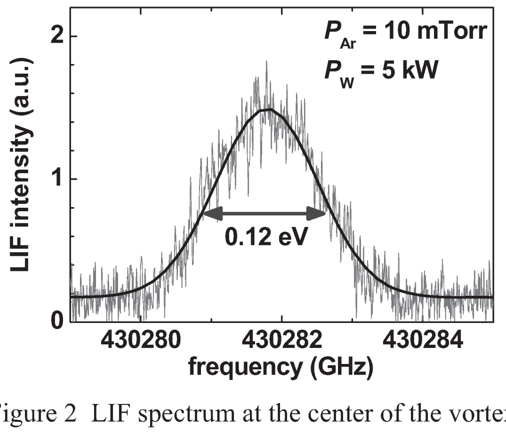

Figure 2 LIF spectrum at the center of the vortex

1) A. Okamoto, et al., Phys. Plasmas **10**, 2211 (2003).