§3. LIF Measurement of Neutral Flow Associated with a Vortex Structure

Ogiwara, K., Etoh, S., Terasaka, K., Tanaka, M.Y. (Kyushu Univ.),
Aramaki, M. (Nagoya Univ.),
Yoshimura, S.

Flow structure in a plasma is usually affected by E×B drift. However, a class of vortices, which rotates opposite to the direction of E×B drift, has been observed in a magnetized argon plasma in the HYPER-I device.[1] This vortex (referred to as anti-E×B vortex) is accompanied by neutral depletion in the center of the plasma, while the plasma density becomes three times higher than that in the peripheral region. The neutral particles flow inward and the ions flow outward due to their density gradients. The outward momentum of ions is changed by the inward momentum of neutrals through charge exchange collisions, and the resultant force generated in this process drives the anti-E×B drift. To experimentally clarify the influence of neutral flow on the anti-E×B vortex formation, we have measured flow velocity field of the neutrals. Neutral flow may also play an important role in dynamical behavior of plasma, such as blob transport in boundary plasmas.[2] Therefore the visualization of neutral flow velocity field has been attracting common interest.

To obtain flow field of neutrals, we have developed a LIF Doppler spectroscopy system. To measure slowly flowing neutrals (~10 m/s), narrow bandwidth and accurately specified wavelength are required for laser light source. We introduced an external cavity diode laser (Toptica DL100) into our LIF system. The spectral bandwidth of the laser is a few MHz and is narrow enough to measure the velocity distribution function of neutrals, whose spectral broadening is expected to be about 1 GHz. A reference frequency is needed for achieving good accuracy in Doppler shift measurement. For this purpose, we combined saturated absorption spectroscopy (SAS) with LIF spectroscopy for the first time.[3]

We have measured LIF spectra (velocity distribution functions) of argon metastable state ($4s[3/2]^o_2$) by tuning the laser wavelength to 696.735 nm. Argon metastable atoms are excited to the upper energy level ($4p[1/2]_1$), and then de-excite to the $4s[1/2]^o_1$ state. The fluorescence photons due to this transition (826.45 nm) are detected using a photomultiplier tube (PMT). The laser beam is modulated to a rectangular wave train with 100 kHz by an electro-optical modulator (EOM) so as to improve the S/N ratio by lock-in detection. We have simultaneously recorded fringes of a Fabry-Perot interferometer (FPI), SAS spectrum and the LIF spectrum for calibration of the laser frequency. In our experiments, three Lamb dips appear at the peak of the absorption spectrum, and the frequency of the center Lamb dip is used as the reference frequency which corresponds to the origin of velocity axis of neutrals.[3] The overall accuracy of the new LIF Doppler system is ±3 MHz, corresponding to velocity resolution of ±2 m/s.

The plasma was generated and sustained by electron cyclotron resonance (ECR) heating of argon gas with a pressure of 10 mTorr. In the presence of anti-E×B vortex, the electron temperature and density measured with a Langmuir probe are about 5 eV and 10^{12} cm^{-3}, respectively.

We observed the radial velocity distribution functions (RVDFs) and the azimuthal velocity distribution functions (AVDFs) of the argon metastables. Figure 1 shows a LIF spectrum (RVDF) at the center of anti-E×B vortex. The temperature of metastable atoms is estimated to be 0.08 ~ 0.09 eV, which exhibits a small peak at the center of the vortex. We calculated the flow velocities of neutrals from the Doppler shift of LIF spectra. The radial flow is directed to the center of the vortex with its maximum velocity of about 40 m/s at r = 4 cm, which agrees with position of the steepest density gradient of the radial profile of neutral density. The azimuthal flow pattern is similar to that of the ion flow, namely, the rotation of azimuthal flow is the same as anti-E×B direction in the center of vortex and is E×B direction outside. We have demonstrated that the new LIF system with a diode laser combined with saturated absorption spectroscopy is a powerful tool for visualizing neutral flow velocity field.

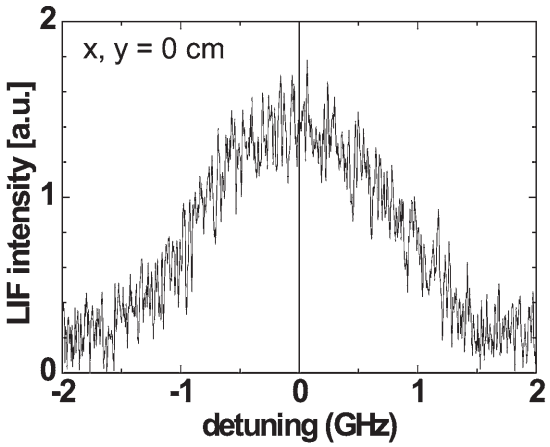

Fig. 1. LIF spectrum of argon metastable atoms in the center of anti-E×B vortex.

1) Okamoto, A., et al., Phys. Plasmas **10** (2003) 2211
2) Krasheninnikov, S.I., Smolyakov,A.I., Phys. Plasmas **10** (2003) 3020
3) Aramaki, M., et al., Rev. Sci. Instrum. **80** (2009) 053505