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Plasma Physics Study Using New Photonics Technology
光科学を融合した新しいプラズマ物理研究

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In the past decades, a lot of useful techniques have been developed in the field of photonics research. By using these technique, we can obtain an extreme condition plasma, or measure plasma parameters with very high precision. In this talk, the study of laser-cooled plasma and neutral gas flow measurement in ECR plasma will be briefly presented. These are the examples of the precise Doppler spectroscopy using a plane wave laser. The plane wave laser cannot detect the movement on the plane perpendicular to the wave propagation. Recently, topological light (so-called "optical vortex") is intensively studied in the field of photonics. Since the optical vortex has a three dimensional phase structure, the motion in the optical vortex induces the Doppler shift in all the three dimensional directions. We also talk about the ongoing development of the optical-vortex Doppler spectroscopy method to break the limitation of the traditional plane-wave Doppler spectroscopy.

1. Introduction

In the past decades, a lot of extreme laser techniques have been developed, and most of them are based on the control of the laser parameter in time-domain and frequency-domain. On the other side, the topology of laser parameters in spatial-domain has not been so much utilized so far. Recently utilization of the structure of phase and polarization in spatial-domain is attempted in photonics field. The structured laser light will add new functions to the traditional laser applications in the plasma research.

The available wavelength of commercial laser diodes is getting wider, and the external-cavity diode laser (ECDL) setup has become a useful tool for the atomic physics [1]. Since the emission of the ECDL is narrow line width and tunable, the velocity distributions of ions and atoms in plasma become accessible using the compact, economic laser source. In this talk, the study of strongly coupled plasma and vortex generation in ECR plasma will be briefly presented. These are the examples of the precise Doppler spectroscopy using the ECDLs which is controlled in the frequency-domain. After that, the inevitable limitation of the traditional laser spectroscopy will be mentioned, and then our challenge to the issue will be presented.

2. Precise Plasma Spectroscopy Using ECDLs

2.1 *Study of coulomb screening in a laser cooled strongly coupled plasma*

An ion trap is a suitable device for the study of the effect of inter-particle correlation in plasma, since gas, liquid, and solid phase plasmas are able to be generated under well controlled condition using the laser cooling method without any change of the device. We are interested in the transition of elementary processes between weakly coupled plasma and strongly coupled plasma. Coulomb interaction affects many elementary processes in plasma; therefore, the screening mechanism of Coulomb potential is one of the important issues. Since the laser-cooled plasma is gently controlled by laser, the state of the plasma is very fragile. We developed a low perturbative laser induced fluorescence (LIF) method using a weak probe laser. Quantitative evaluation of the spectrum broadening of the cooled plasma becomes possible by using the system. A series of the spectrum measurements was performed in the range of Γ = 0.1 to 10. We also observed an unexpected broad dip in the some spectra (Fig. 1) [2]. The broad dip imply the higher ion-ion collision frequency than the expected frequency by the Debye screening assumption.

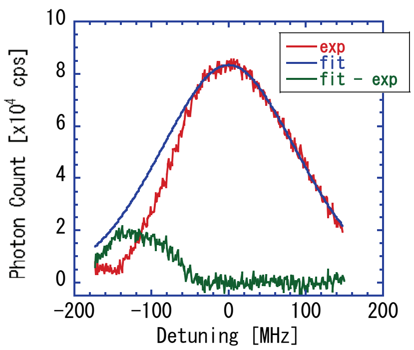

Fig. 1 Probe LIF spectrum.

2.2 Slow *neutral gas flow measurements in an ECR plasma*

Anti-E×B type vortexes have been found in the high density plasma experiment (HYPER-I) device at the National Institute for Fusion Science, Japan. The momentum exchange between neutral atoms and ions is considered to play an important role in the formation mechanism of this type of vortexes. Thus, the measurement of the slow neutral-gas flow is fundamentally important. We developed a high-precision LIF spectroscopy system to detect the neutral flow as the Doppler shift of velocity distribution. The minimum detectable flow velocity of the newly developed LIF system was ±2 m/s [3]. Figure 2 shows the flow field of (a) neutral atoms and (b) ions which were observed using the LIF system and a directional Langmuir probe respectively. The correlation between the flow fields indicates the strong interaction between the neutral atoms and ions in the vortex.

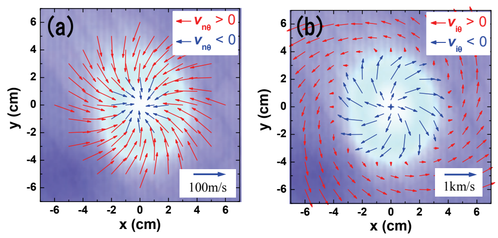

Fig. 2 The flow field of (a) neutral atoms and (b) ions.

3. Inevitable Limitation of Plane Wave Laser Spectroscopy, and a Solution by Using Structure of Light

Practically, we often assume laser light to be a plane wave. As shown in Fig. 3 (a), phase of plane wave changes only in the direction of wave propagation, therefore the movement on the plane perpendicular to the wave propagation does not induce the Doppler shift and, of course, cannot be detected by the Doppler spectroscopy. It is one of the limitations of plane wave laser spectroscopy which have been accepted as inevitable results. Recently, utilization of the structure of phase and polarization in spatial-domain is attempted in photonics field. Figure 3 (b) and (c) show so-called optical vortex and polarization vortex. The optical vortex is intensively studied in the field of a high resolution microscopy, optical tweezers, etc. However, its potential for plasma diagnostics has not been studied yet. Its three dimensional phase structure is valuable for the multidimensional Doppler spectroscopy, since the motion in the optical vortex induces the Doppler shift in all the three dimensional directions [4].

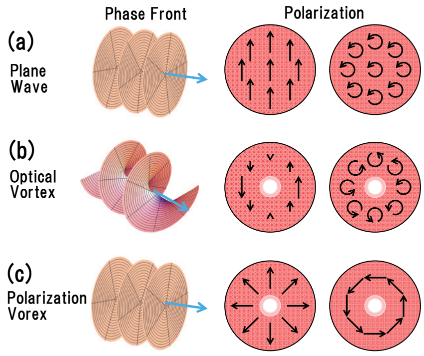

Fig. 3 Phase front and polarization of (a) plane wave, (b) optical vortex, and (c) polarization vortex.

4. Multidimensional Laser Spectroscopy Using Optical Vortex

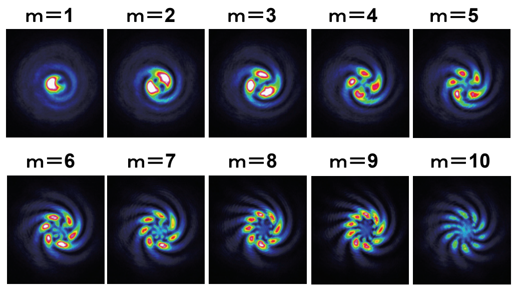

Fig. 4 Interference pattern between a optical vortex and a spherical wave.

We aim to develop a three dimensional Doppler spectroscopy method using the optical vortex. We have developed a tunable optical vortex laser using a computer-generated hologram (CGH) displayed on a spatial light modulator (SLM). Figure 4 shows the interference pattern between the optical vortex and a spherical wave. Since the phase of the optical vortex varies $m \times 2\pi$ in the cross section, the interference patterns show m bright points. Since the azimuthal Doppler shift is proportional to m, the higher order optical vortex is preferred for the spectroscopy. The latest experimental results of the optical vortex laser spectroscopy will be presented.

Acknowledgments

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