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Plasma Polarization Spectroscopy on the ECR helium plasma in a cusp magnetic field

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Abstract

Helium emission lines have been observed on the ECR plasma in a cusp field with the polarized components resolved. The polarization map is constructed for the 501.6 nm (2^1S-3^1P) line emission. Lines from n^1P and n^1D levels are strongly polarized and those from $n\,^3D$ levels are weakly polarized. As the helium pressure increases the polarization degree decreases.

1. Introduction

In plasma, electron heating which accelerates electrons to a particular direction together with a trapping of electrons in a magnetic field may make the electron velocity distribution function (EVDF) anisotropic. Intensity and polarization of emission lines from excited levels, which are produced by electron-atom collisions, are the result of the EVDF. Especially the polarization strongly reflects the anisotropy of the EVDF.

Since the propagation of errors from measured intensities to the polarization degree tend to make its error large, it is difficult to measure a polarization degree less than 0.1. In the following we report our first observation on a reproducible and stable plasma and determination of polarization degrees with relatively small errors.

2. Experiment

Figure1 shows the cusp plasma generator. Helium gas pressure is from 1.7×10^{-4} to 2.0×10^{-3} torr. Two coils (900 A) generate a cusp field. The magnetic field is strong in the outer regions of the plasma. The field strength of the chamber wall near the coils is about 3000 G. The electrons tend to be trapped in the central part of the plasma. Microwaves (2.45 GHz, 800 W) enter through the upper quartz window into the chamber and generate virtually stationary plasma for four seconds. The electron cyclotron resonance (ECR) surface is a spheroid. The stuffer conductor is not used in our present experiment. We have a probe in the camber and it gives plasma parameters. When helium pressure is 1.7×10^{-4} torr the electron temperature and the electron density are 20 eV and 1×10^{17} m^{-3}, respectively, in the middle.

In front of the lens of a digital camera, we placed a band pass filter (center wavelength

501.8 nm, bandwidth 1.5 nm, transmitting He I 501.6nm (2^1S-3^1P) line) and took a photograph of the area marked (a) in Fig.1. Figure 2(a) shows the photograph. Figure 2(b) shows the magnetic field lines and the ECR surface. It is seen that the plasma is formed along the magnetic field lines. We then placed a linear polarizer in front of the camera system and took photographs by changing the polarization direction of the transmitted light. Thus, we obtained the spatial distribution of the intensity of four linearly polarized components I_0, I_{45}, I_{90}, I_{135}, the polarization direction of which are 0, 45, 90, 135 degrees from the vertical direction. We thus determined the linear polarization components of the Stokes parameters $Q = I_0 - I_{90}$ and $U = I_{45} - I_{135}$. We assume the circular polarization components to be $V = 0$. From these distributions we determined the distribution of the polarization direction and degree as shown in Fig. 2(c). The polarization direction is perpendicular to the magnetic field. This result suggests that the electron velocity distribution is anisotropic: the velocity component perpendicular to the magnetic field is stronger.

In order to investigate the polarization characteristics of our plasma quantitatively, we observe several emission lines on the four areas shown in Fig. 2(b) by using an optical system with a Glan-Thompson prism and optical fibers. Figure 3 shows the side view of the chamber and the optical system. We observe the plasma by four lines of sights (LOS 1, 2, 3 and 4). The LOS 4 is near the ECR surface. The emission radiation transmitted through the quartz window is resolved into two linearly polarized components (π component parallel to the magnetic field and σ component perpendicular to the magnetic field) by the Glan-Thompson prism and focused on the four pairs of optical fibers (core diameter ϕ400 μm, length 8 m) by a lens (f = 50 mm). The exit light from the fibers enters through the entrance slit of the spectrograph, (Nikon G500, f 500 mm, grating 1200 grooves/mm, F/8.5) resolved and recorded by the ICCD.

Figure 4 shows an examples of the spectra for the helium pressure of 1.7×10^{-4} torr. The left panel is for LOS 1 and the right one is for LOS 4. The π components are displaced to the right. The lines included are 492.2 nm (2^1P-4^1D), 501.6 nm (2^1S-3^1P) and 504.8 nm (2^1P-4^1S). The upper level of the 504.8 nm line is a ^1S level, so that the emission is never polarized. Apparent different intensities for this line are due to different sensitivities of our detection system for the polarized components. We calibrated our system by using a calibrated standard irradiance lamp and a white reflectance standard. It is seen that other two lines are polarized.

3. Analysis

The spectra shown in the left-side panels of Fig. 5 are LOS 2 observed at different helium pressures. In the lower graph the helium pressure is higher. From these spectra we determine the longitudinal alignment $A_L = (I_\pi - I_\sigma)/(I_\pi + 2I_\sigma)$ to quantify the polarization degree.

We repeated the measurement several hundred times and obtained the histograms shown in the right-side panels of Fig.5. The unpolarized line is used to determine the zero point of the A_L scale. As the helium pressure increases the polarization degree decreases.

We now examine these distributions in detail. The histograms follow quite well the normal statistical distribution, and the dispersion depends on the line intensity. Intensity of the 501.6 nm line is higher than others, and the dispersion of this line is smaller. This is consistent with statistical fluctuations of photon numbers. Since we have enough numbers of experimental data, the statistical uncertainty is quite small. If the polarization itself fluctuates, the central value should fluctuate, and the dispersion should be wider. In our experiment, intensities of the polarized 492.2 nm line and unpolarized 504.8 nm line are almost equal and the dispersions of their distributions are essentially the same. We can conclude that the polarization degree is quite reproducible, which means that the anisotropic distribution of electrons is quite stable.

In Fig. 6 we plot the pressure dependence of A_L for all the LOSs. Statistical uncertainty is smaller than the size of the symbols. Here we note the three points. First, with an increase in the helium pressure A_L comes close to zero. Second, A_L of the 492.2 nm line is almost the same for all the line of sights. Third, A_L of the 501.6 nm line is larger outside than close to the ECR surface.

Figure 7 shows the energy level diagram of neutral helium and emission lines for which we determined intensities and A_Ls. The emission lines represented by the broken line are those the A_L of which is calibrated with an unpolarized line from a ^{1}S level. The A_L comes from the alignment, or the population imbalance among the magnetic sublevels, of the upper level population. Figure 7(a) shows A_L with bar originating from the position of the upper levels of the emission lines. All values are negative. Emission lines from ^{1}P and ^{1}D levels are strongly polarized and those from triplet levels, especially from higher excited levels, are only weakly polarized. The line intensity itself is another important quantity. The intensity comes from the population of the upper level. We determine the population, n, with $I_\pi + 2I_\sigma = n(p)\,\chi_{pq} A_{pq}$. Here χ_{pq} is the photon energy and A_{pq} is Einstein's A coefficient. Figure 7(b) shows the distribution of populations in the log scale. Population has been divided by the statistical weight.

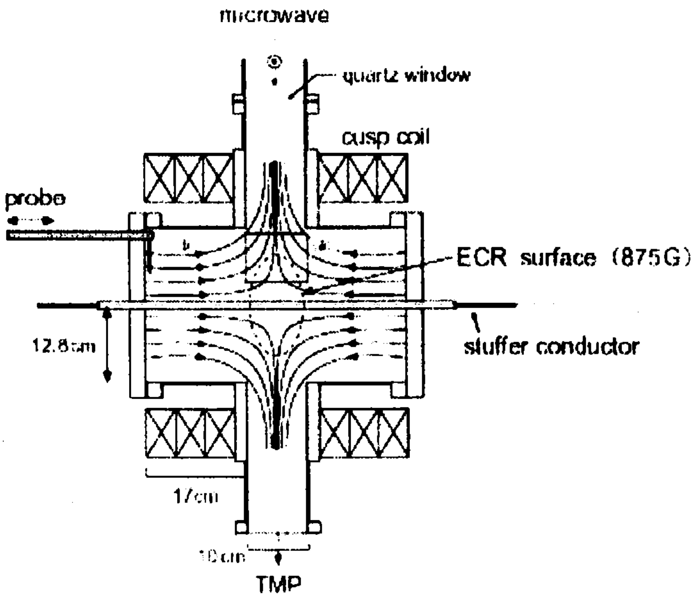

Fig. 1. The front view of the plasma generator.

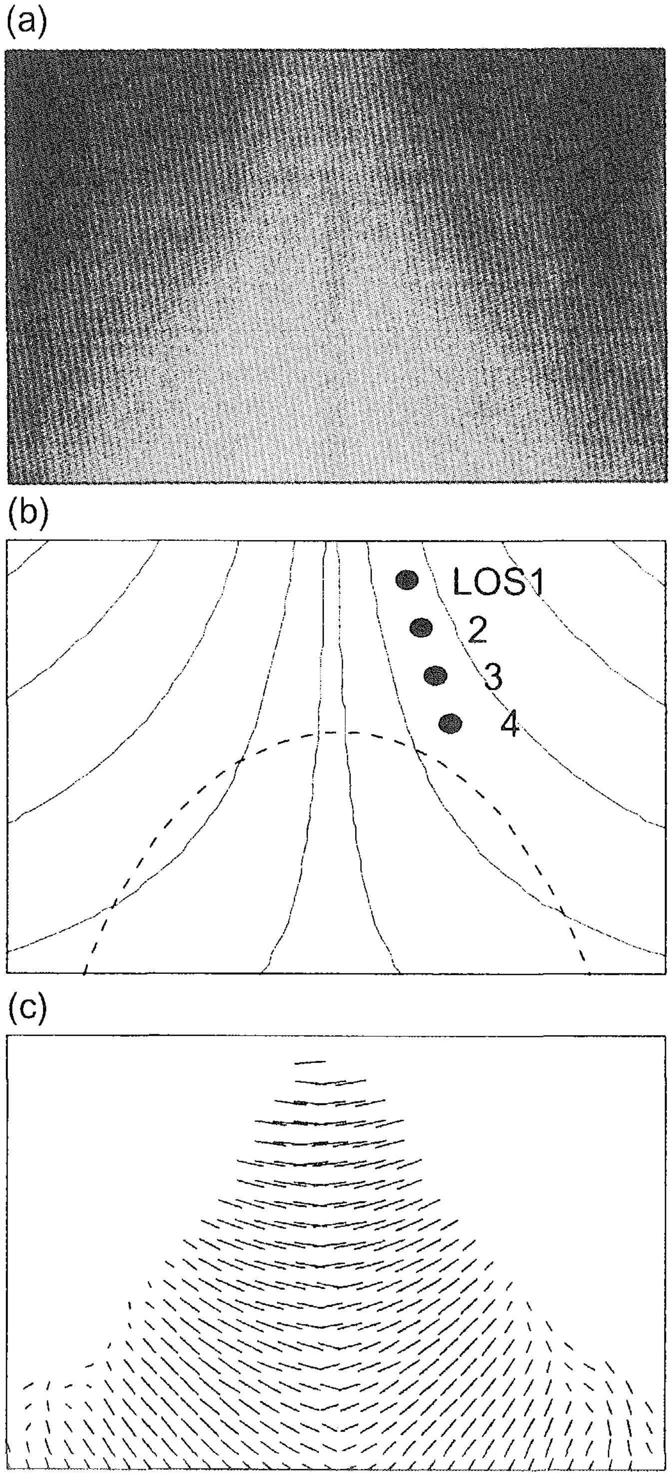

Fig. 2. (a) An example of He I 501.6nm (2^1S-3^1P) line images of area (a) in Fig.1. (b) The magnetic field lines (solid lines), the ECR surface (broken line) and the line of sights (LOS) of the optical system with the Glan-Thompson prism and optical fibers in the area. (c) Polarization map for the 501.6 nm line. The lines indicate the polarization direction and the length of the lines are proportional to the square root of the polarization degree.

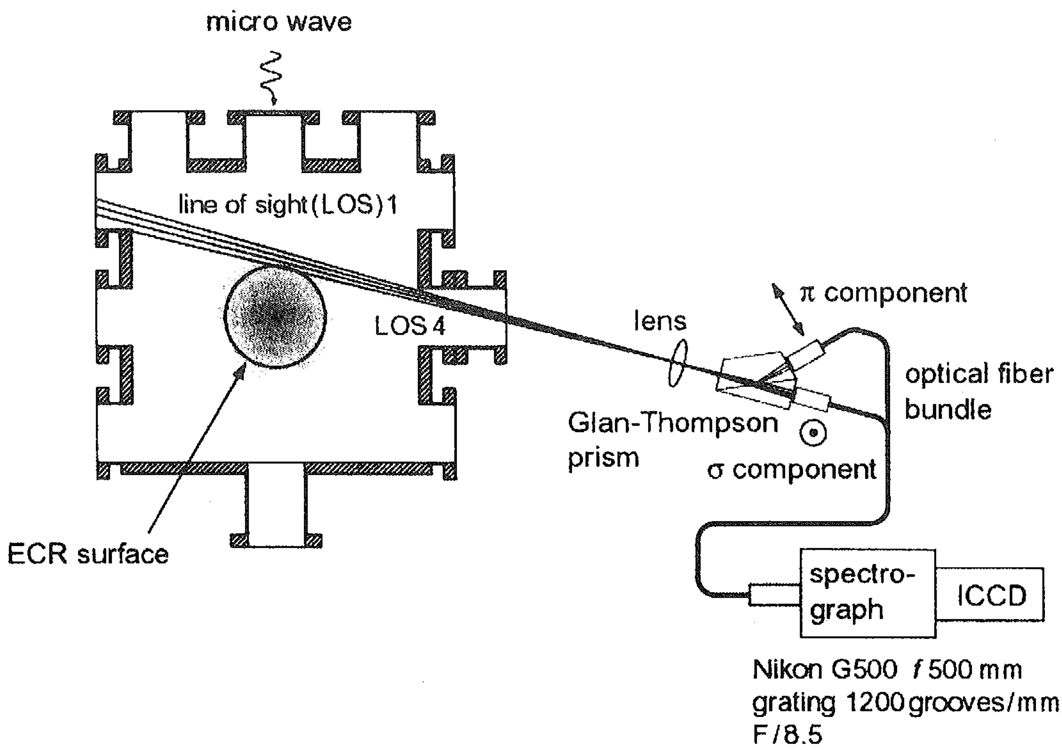

Fig. 3. The side view of the chamber and the optical system.

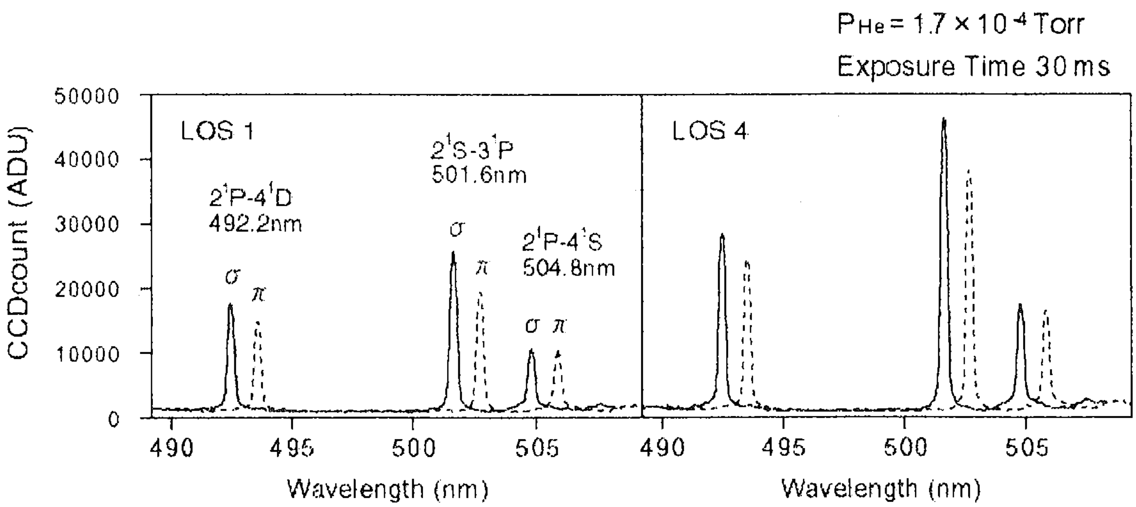

Fig. 4. An example of the spectra of the σ component (solid line) and the π component (broken line) when helium pressure is 1.7×10^{-4} torr. The left panel is for LOS 1 and the right one is for LOS 4. These indicate 492.2 nm (2^1P-4^1D), 501.6 nm (2^1S-3^1P) and 504.8 nm (2^1P-4^1S) lines. The π components are displaced to the right.

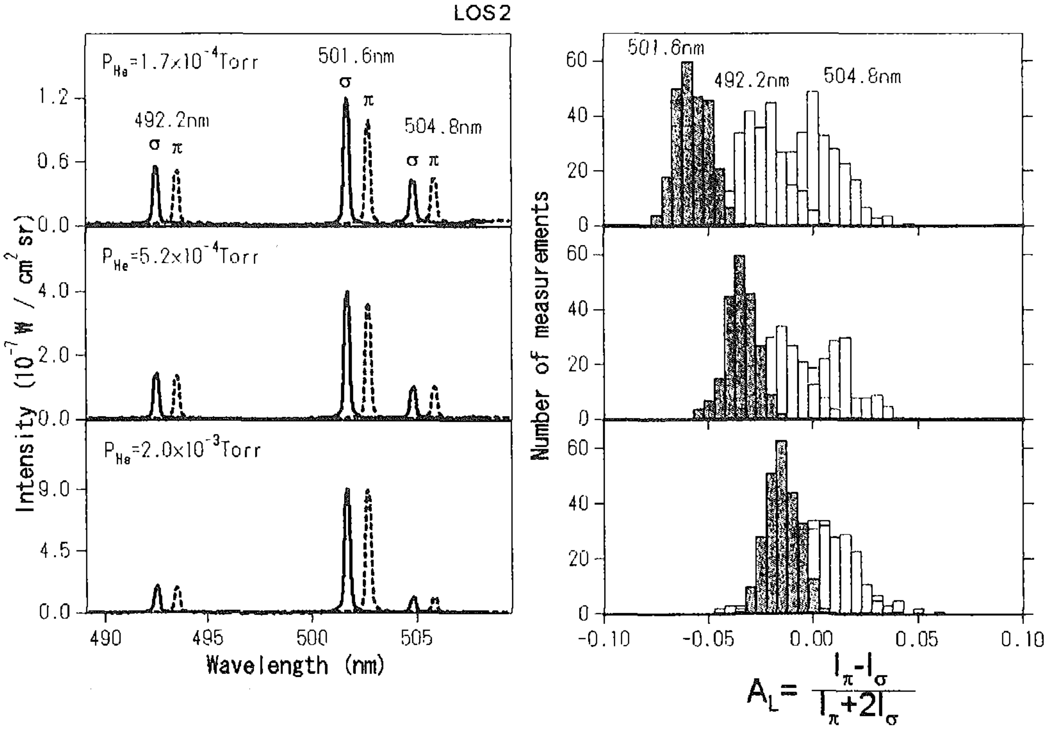

Fig. 5. The spectra for the line of sight 2 observed at different helium pressures and the corresponding histograms of the longitudinal alignment $A_L = (I_\pi - I_\sigma)/(I_\pi + 2I_\sigma)$.

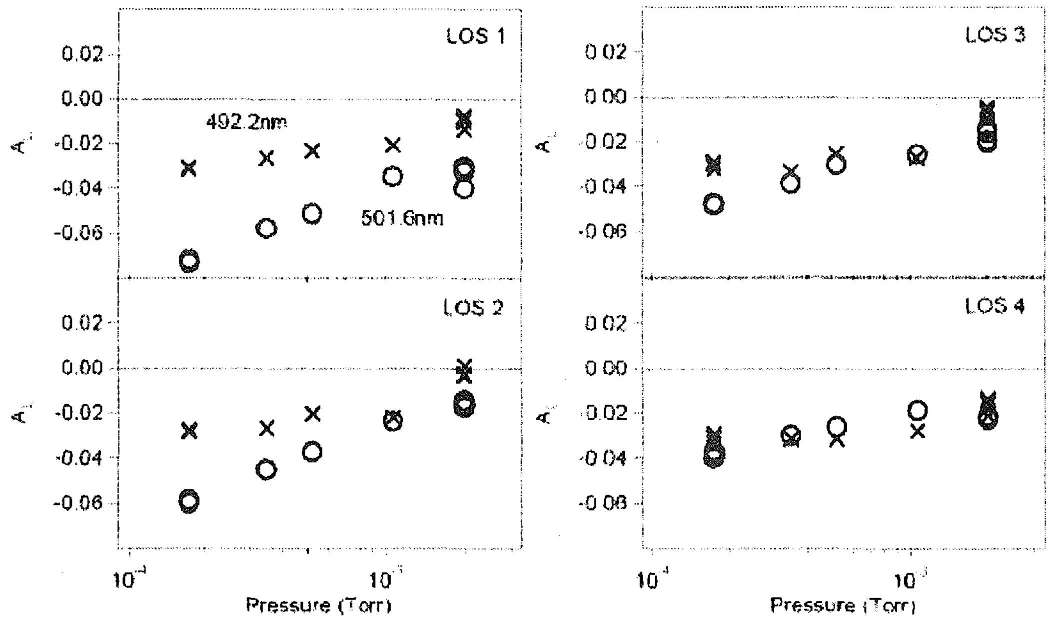

Fig. 6. The pressure dependence of the A_L of 492.2 nm line (cross) and 501.6 nm line (circle) for all the LOSs.

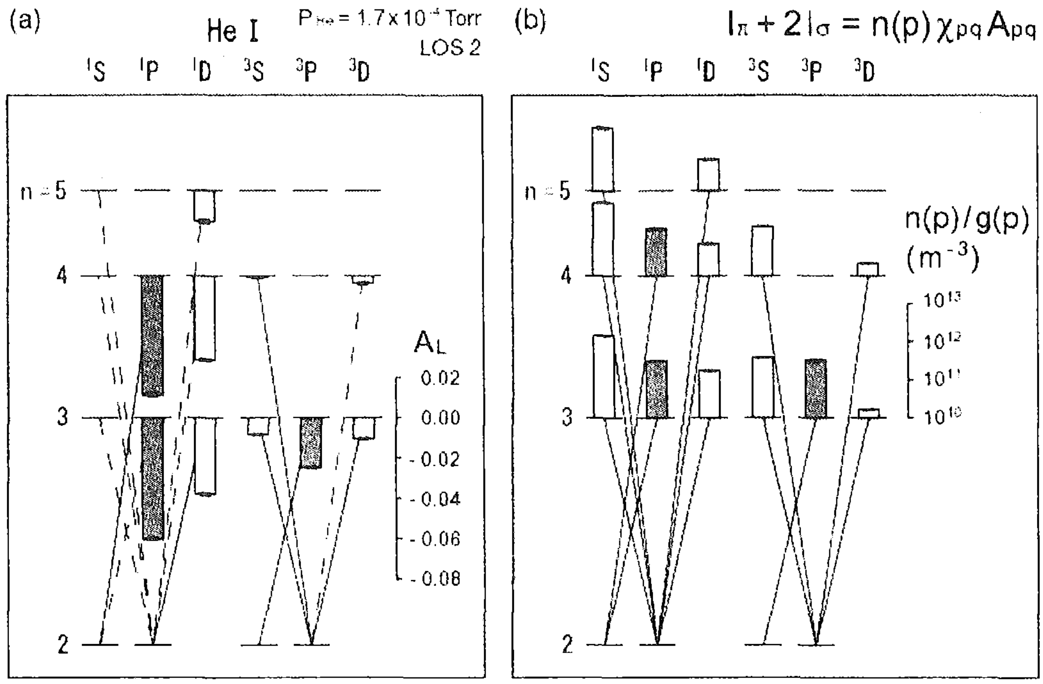

Fig. 7. The energy level diagram of neutral helium and emission lines for which we determined intensities and A_Ls. The emission lines represented by the broken line are calibrated by unpolarized line from a ^{1}S level. (a) A_L expressed with a bar originating from the position of the upper levels of the emission lines. (b) The distribution of populations in the log scale.