Magnetic Field Dependence of Plasma Properties Observed with Tomography in PANTA

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The magnetic field dependence of a linear argon plasma is examined with a tomography system in PANTA. It is found that a plateau region exists around a particular region of magnetic field (~600 G), below and above which the plasma changes the properties of emission and its fluctuations. A model is proposed to explain the observed dependence, and the comparison demonstrates that the dependence should be ascribed to the change in the Lamor motion inside the plasma production source using helicon wave and the plasma transport after the production.

Keywords: magnetized helicon plasma, plasma production, tomography, plasma emission, fluctuation

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Helicon-wave antennas are often used as a convenient source to produce plasmas such as plasma processing, plasma basic experiments and so on [1]. Such a source is being used for a linear cylindrical plasma, Plasma Assembly for Non-linear Turbulence Analysis (PANTA) [2]. In PANTA, tomography systems have recently started working to provide two-dimensional (2D) plasma emission and its fluctuations without any perturbation to plasma [3]. The article presents the magnetic field, B, dependence of plasma emission and fluctuations observed with tomography. The results indicate that the properties clearly change around B~600 G. A model is proposed to suggest that the changes should be ascribed to the Lamor motion in the helicon source and plasma transport in the vacuum chamber.

The PANTA device produces linear cylindrical plasmas whose diameter is approximately 100 mm and axial length is 4000 mm with helicon double loop antenna at 7 MHz. The device can produce a homogeneous and straight magnetic field up to 0.15 T. The center of helicon source is located 30 cm away from the nearest coil. The tomography system in the present experiment can measure the entire plasma cross-section in the square region of 10 cm × 10 cm. The data is reconstructed using Maximum Likelihood Expectation Maximization (MLEM) method.

The experiment is performed with the filling argon gas pressure and the production power at 3 mTorr and 3 kW, respectively, with B = 100 G to 1300 G by 100 G. Figures 1 (a) and (b) show the dependence of the plasma emission, *i.e.*, the total emission, ϵ_t, and the effective extent, $\bar{r}$, defined as $\bar{r}^2 = \langle (r/a)^2 \rangle = \int (r/a)^2 \varepsilon_s(r) dr / \int \varepsilon_s(r) dr$, with the symmetric part of the profile, $\varepsilon_s(r)$. As B increases, the total emission increases monotonically with peaking the profile below ~600 G to show a plateau, then it starts increasing above ~800 G again with broadening the profile above ~1000 G.

Figures 1 (c) and (d) show the B-dependence of the power spectral density of the total emission with fluctuation patterns. Figure 1 (c) shows that the existence of clear coherent peaks changing their frequencies and the corresponding azimuthal mode numbers. The azimuthal number of the dominant modes is m = 0 for every coherent mode below ~500 G. On the other hand, above ~700 G, the dominant one is m = 1 for the fundamental modes with lowest frequency, while each mode with the harmonic frequency is confirmed, as is clearly shown in Fig. 1 (d), to have the harmonic azimuthal number. The patterns are deduced with Fourier-Bessel function series [4].

A primitive model is proposed to explain the overall $\varepsilon_s(r)$-dependence, particularly the existence of plateau. The model uses the assumptions; i) the emission is expressed as the square of the ion density n_i, *i.e.*, $\varepsilon_s(r) \propto n_i^2(r) \sim n_e n_i$, ii) the ions are born with a birth rate, $S_p(r)$, decreasing toward the source wall with the Maxwellian distribution, and iii) the ions with larger Lamor motion cause the collision with the source wall, and the ions without the collision can survive into the chamber. Thus, two kinds of ions can survive; the ones with the sufficiently small Lamor radius less than distance to the wall (called here slow ions), and the others with the sufficiently paral-

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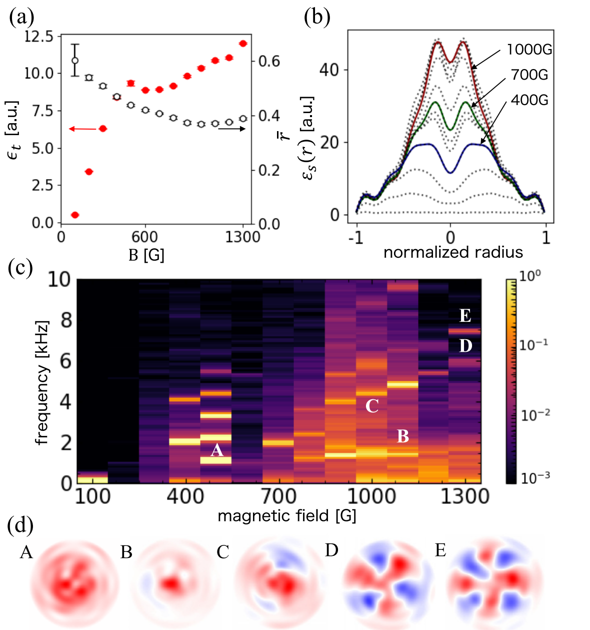

Fig. 1 The magnetic field dependence of plasma emission properties observed with tomography. (a) The total emission and the effective radial extent, and (b) the emission profile (symmetric part). (c) The fluctuation spectra, (d) the observed patterns of the coherent mode fluctuations. From the left hand side, the patterns at (f, B) = (1.1, 500), (1.4, 1100), (2.8, 1000), (6.0, 1300), and (7.4 kHz, 1300 G).

lel velocity against larger Lamor radius (called fast ions). Note that the first assumption is based on the fact that electron temperature profile and its absolute value show no significant dependence in PANTA.

The local surviving rate is described as $S(r) = S_p(r)(p_\perp(r) + (1 - p_\perp(r))p_\parallel(r))$, where $S_p(r)$ is the local birth rate, and the first and second term on the right hand side correspond to the contributions of the slow and fast ions, respectively. The probabilities are expressed as

$$p_\perp(r) = \frac{m}{kT}\int_0^{v_{C\perp}(r)} \exp\left[-\frac{mv_\perp^2}{2kT}\right] v_\perp dv_\perp, \tag{1}$$

$$p_\parallel(r) = \sqrt{\frac{m}{2\pi kT}}\int_{v_{C\parallel}(r)}^{\infty} \exp\left[-\frac{mv_\parallel^2}{2kT}\right] dv_\parallel, \tag{2}$$

where m, k, T, r, and a represent the ion mass, Boltzmann constant, the ion temperature, radial position of the production, and the radius of the source, respectively, with $v_{C\perp}$ and $v_{C\parallel}$, are the marginal perpendicular and parallel velocity for the slow and fast ions, respectively. These velocities satisfy, $v_{C\perp} < \omega_L d/2$, $v_{C\parallel} > L\omega_L/2\pi$ with ω_L, d and L being the Lamor frequency, the distance between the ion and the wall and the length of the source, respectively.

Then, the total surviving rate, S_0, is described as $S_0 = L\int_0^a S(r)\pi r dr$. After the production, the ions should decay due to recombination and radial diffusion. Assuming no profile changes, the plasma number in the chamber, $N_p = \tau S_0$, is obtained, where $\tau = \frac{\tau_{rec}\tau_D}{\tau_{rec}+\tau_D}$ with τ_{rec} and τ_D being the recombination and diffusion time, respectively.

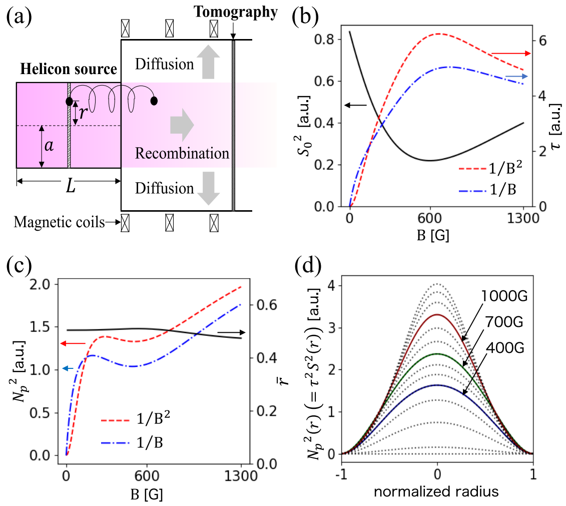

Fig. 2 (a) A schematic view of helicon source and vacuum chamber of PANTA. (b) Total number of the produced plasma and decay times. (c) The calculated total intensity of emission assuming the radial diffusion with $1/B$ and $1/B^2$ dependence and the effective radial extent. (d) The calculated profiles.

Figure 2 shows the calculation results with a schematic view of the source. The assumptions are made; i) the volume-averaged magnetic field inside the source, 1/5 of its maximum in the chamber with the experimental value of ion temperature, 0.3 eV, ii) the local birth rate takes the function form as $S_p(r) = (1 - r^2)$, which incorporates the effect of electron temperature substantially, and iii) the recombination time, $\tau_{rec} = const/S_0$, and two cases for the radial diffusion times of $\tau_D = 2.91 \times 10^2 B$ and $\tau_D = 1.94 \times 10^4 B^2$, which reflect the overall dependence of the fluctuation driven and collisional diffusion, respectively. The model reproduces a qualitatively similar tendency to the experiment, *i.e.*, the existence of a plateau and the behavior below and above the plateau. The constant radial extent in calculation could be fixed if plausible radial diffusion is taken into account.

Finally, the dependence of the plasma emission including the existence of the plateau can be well explained by a combination of the changes in B-dependence of the plasma generation and the radial diffusion, although the model needs further confirmation. The results also give a hint that the drastic change of the fluctuation properties, as is shown in Figs. 1 (c) and (d), can be associated with the difference in the ion velocity distribution. The presented model suggests that the velocity distribution could recover from the dominancy of parallel component to more isotopic one. The change may cause a different kind of instabilities.

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